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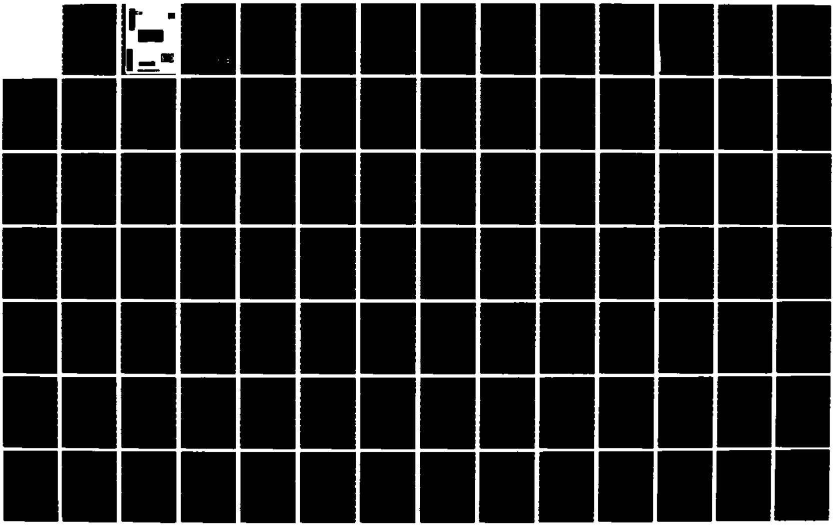

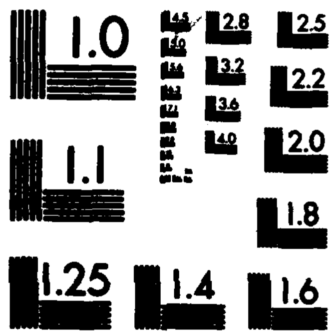

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FINAL REPORT

DEVELOPMENT AND EVALUATION
OF A BAYESIAN
SEQUENTIAL TESTING METHODOLOGY
FOR ASSESSING THE RELIABILITY
OF DEFENSE SYSTEMS

MAXIMUS

March 22, 1978

FINAL REPORT

DEVELOPMENT AND EVALUATION OF A BAYESIAN SEQUENTIAL TESTING METHODOLOGY FOR ASSESSING THE RELIABILITY OF DEFENSE SYSTEMS

"This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Office of Naval Research under Contract N00014-76-C-0074 under subcontract from Decisions and Designs, Inc."

MAXIMUS, INC.
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MAXIMUS

TECHNICAL CONSULTANTS TO MANAGEMENT

March 22, 1978

Lt. Col. Roy M. Gulick
Advanced Research Projects Agency
Cybernetics Technology Office
1400 Wilson Boulevard
Arlington, Virginia 22209

Dear Col. Gulick:

With this letter, I am pleased to transmit the Final Report of our contract for the "Development and Evaluation of a Bayesian Sequential Testing Methodology for Assessing the Reliability of Defense Systems."

This Report is organized into five parts:

PART 1 provides an introduction and summary of the Project, reviewing its objectives and accomplishments.

PART 2 describes one example of the theoretical savings that can be achieved for a simple system when a cost-effective test plan is adopted.

PART 3 is a User's Manual for the FORTRAN IV computer program developed in this project for carrying out Bayesian reliability assessments and for implementing the sequential testing methodology.

PART 4 presents a directory of organizations in the Department of Defense involved in reliability assessment and the results of a survey on their attitudes to Bayesian reliability assessment.

PART 5 provides a copy of the briefing charts used to explain the project to various members of the Armed Services.

We have thoroughly enjoyed working on this contract with you and Dr. Clinton Kelly of Decisions and Designs, Inc. Possibly, we have made a worthwhile contribution to Bayesian reliability assessment and the concept

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of cost-effective testing in general. We hope to continue our efforts in this field and look forward to the opportunity of making future contributions to the Department of Defense.

Any comments you may have on the report will be most welcome.

Yours truly,

David V. Mastran

David V. Mastran
President

DVM/es
Enclosure

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"The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Research Projects Agency or of the United States Government."

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PART 1

INTRODUCTION AND SUMMARY

PART 1

INTRODUCTION AND SUMMARY

In the first part of the Final Report we review the concept of cost-effective testing, the basic objective of this Project, the task plan followed, and the accomplishments at completion.

I. CONCEPT OF COST-EFFECTIVE TESTING

The concept of cost-effective testing of multi-component systems is central to this Project. The concept arose from a study of the testing of operational systems aimed at detecting the degradation of component reliabilities over time. This type of testing is usually conducted on a continual basis by system users to guard against the erosion of system reliability due to aging. Typically, the system, consisting of various subsystems or components, is brought in from the field for testing. The components are then tested in two ways: either independently in component-level tests, or simultaneously in system associated tests. —> cont. to pg -3-

As these systems are brought to the test facility, each component in the system is tested. As a result, the total number of tests on each component is a direct function of the number of times it appears in the system. Testing all the components in the system does not consider the variations in both the cost and value of the information obtained from testing each component. These variations can be important in developing a cost-effective test plan, especially when one is faced with a limited test budget.

The concept of cost-effective testing also extends to other types of testing, including, for example, production-line testing. As items are manufactured in production lines and aggregated into lots, they are tested by the contractor and/or government personnel for the purpose of accepting or rejecting the lot. These components are then combined into larger and larger assemblies which are also aggregated into lots and tested. The largest assemblies are combined into subsystems and are tested again. Areas that offer possible reduction in testing costs are avoiding duplicate testing and designing lot sizes to consider the serial correlation in lot test results. Thus, the process of testing multicomponent systems cost-effectively is a much more difficult problem than testing components independently.

The savings achievable from cost-effective testing can occur in a number of different ways. Under certain circumstances, it may be advantageous to test some components in the system much more than others, or not to test some components at all. For example, some components might be more costly to test than others; in destructive testing, the component has to be replaced. In other cases, special test equipment or procedures are required, or components are inaccessible, and, therefore, costly to remove or monitor. In still other cases, more information (both objective and subjective) might be available on some components than on others. (As systems evolve other time, components from the preceding generation of the system often are used

in the current generation; consequently, past test data and engineering judgment are available and can be used to reduce testing requirements. Or, because of the component's position in the system and number of redundancies, some components may be more critical to the successful functioning of the entire system and, hence, should be tested more than others. Components in series, obviously, are the most critical.

cont In sum, there are a number of reasons why it is possible that all components in the system should not be tested the same or a proportionate number of times. The purpose of this project is to evaluate a Bayesian sequential testing methodology that considers these reasons and balances the costs of testing with the expected value of the information to be gained. The methodology indicates in sequential form which component or subsystem in the system to test next, and when to stop testing. This test plan developed should provide estimates of the reliability of complex systems more cost-effectively than the plans typically used.

The methodology examined in this project uses a sequential testing scheme for obtaining attribute (pass-fail) test data from components of multi-component systems. The components in the system can be configured in any manner whatsoever, assuming that the reliability of the system can be expressed as a function of the reliabilities of the components. The selection of the prior distribution of component reliabilities and the form of the loss function are also completely flexible.

The objective of the cost-effective testing methodology is to present decision rules for minimizing the decision maker's expected loss in terms of future risk and the component testing costs. Bayesian preposterior analysis is used to determine when the cost of testing a component exceeds the savings that can be expected to result from reducing risk. Risk, here, is defined as the expected loss due to mis-estimation.

The test plan is constructed as follows. Before a component is tested, a calculation is made to determine if the combination of the future risk and the cost of testing can be expected statistically to decrease. The current value of the risk is known as the prior risk, even though some of the components might have already been tested. The posterior risk is simply the new risk after testing. The prior expectation of the posterior risk is the expected value of the risk before the additional tests are made.

The basic decision is when to stop testing, and if not, which component to test next. The decision process is sequential, test by test, and determines in a series of decision rules which component offers the greatest expected reduction in total loss, given the series of previous test results.

II. OBJECTIVE OF THE PROJECT AND TASK PLAN

The basic objective of this project was to evaluate the cost savings potential of a testing plan developed for multi-component systems,

considering the cost and value of the information obtained from testing selected components. The methodology, which was partially developed at the time the project began, promised to result in significant savings in the cost of testing and greater precision in the estimates obtained from testing. Four basic tasks were undertaken.

Task 1: Review Current Service Testing Programs and Refine Methodology

In this task, the various testing programs of the Army, Navy, and Air Force were surveyed concerning the nature and structure of their testing programs and their attitudes toward Bayesian analyses. We wished first to insure that the Service program selected for this project was receptive to demonstrating the advantages of the methodology. Second, we desired to gain a greater understanding of the variety of organizations in each service involved in reliability assessment. The results of the survey and a directory of these organizations are presented in Part 4 of this report.

Task 2: Develop Computer Programs for Implementing Methodology

Experience has shown that a sophisticated decision analysis methodology has a better chance of implementation if it is supported by computer software. In this task, we developed a computer program which would facilitate the development of a cost-effective test plan. The program named ABRAM (Automated Bayesian Reliability Assessment Model) is described in Part 3 of this report.

Task 3: Select a Testing Organization and Instruct the Staff in the Application of the Methodology

In this task, the Army Armament Materiel Readiness Command was selected to participate in the project and implement the methodology on an armament system. A trip was made to Rock Island Arsenal, Illinois, in October, 1977 to explain the computer program and brief key officials on the project. Mr. Louis Iannuzzelli was designated the ARRCOM Project Manager, and Mr. Robert McKeague a project participant. A description of ARRCOM's mission and organizational structure and the actual system selected for test are provided in the briefing charts in Part 5 of the report.

Task 4: Evaluate Organizations' Experience with the Methodology.

This task was to result in a definitive statement of the cost savings potential of the methodology at ARRCOM. Unfortunately, no data were available on the cost of testing components and considerable effort would have been required to collect the data. Because of the limited contract funds and time remaining, and the different type of testing being conducted (production-line vs. surveillance for degradation), it was decided that a theoretical study using simulated data would have to be substituted. Part 2 of this report describes this study and shows that, in fact, substantial savings are possible.

In sum, although the project did not demonstrate on a real system the level of cost savings possible, it did show that such a demonstration would probably be very successful. It also produced a great deal of background material that should be helpful as independent products.

III. SPECIFIC ACCOMPLISHMENTS OF THE PROJECT

The specific accomplishments of the project were as follows. First, a survey was conducted of the receptivity of major testing programs in all the military services to Bayesian reliability assessment techniques. Persons throughout the DoD testing community were briefed on the project, including the Reliability Implementation Group (RIG) in the Air Force. Considerable interest was expressed in the basic concept and further study was recommended.

The organizational structure and composition of the DoD testing community was studied and described for purposes of promoting greater cooperation and understanding of the problems of reliability assessment. The directory produced should also prove valuable for disseminating research findings throughout DoD.

Second, the U.S. Army Armament Materiel Readiness Command (ARRCOM), the organization responsible for the logistical support of armament systems, selected to participate in the study, was briefed on the features of the methodology. ARRCOM, recognizing that the methodology could, in fact, result in substantial savings in test costs, initiated a new effort, Optimum Test at Minimum Cost (OTMC), to assess the advantages of cost-effective testing. A multi-component system (the 81mm HE cartridge M374) was selected for analysis by ARRCOM after consideration of several alternatives, and a data collection plan was developed to obtain information needed to imple-

ment the methodology for proving grounds testing.

ARRCOM became actively interested in trying additional cost-reduction techniques, including methods for combining system and component level data in the same assessment, and has expressed a desire to expand the study to other armament systems.

Third, a computer software package, Automated Bayesian Reliability Assessment Model (ABRAM), for implementing the sequental testing methodology was written and a User's Manual was prepared. This program, structured for use by non-technical users, will facilitate Bayesian reliability assessments for interested organizations.

Finally, a theoretical study was conducted of the potential savings that can be achieved by testing cost-effectively. A simple series/parallel system was used to provide insight into when significant savings can be expected. Under fairly conservative assumptions, a reduction of 61% of the test budget was found possible, suggesting promising results for applications on real systems.

PART 2

DEMONSTRATION OF SAVINGS THAT MAY BE FEASIBLE BY TESTING COST-EFFECTIVELY

PART 2

DEMONSTRATION OF SAVINGS THAT MAY BE FEASIBLE BY TESTING COST EFFECTIVELY

I. INTRODUCTION AND BACKGROUND

The savings that may be achieved by adopting a cost-effective test plan are demonstrated in this part of the report. Since actual cost data were not available in time, simulated data have been used to demonstrate the theoretical savings that are possible. Moreover, because of limited contract funds, only a simple system was evaluated. Hopefully, the results will provide insight into the savings that can be obtained in more complex systems.

Although a complete description of ABRAM, the software program used to compute the savings, is provided in Part 3, a brief review of the assumptions implicit in the program is given here.

The main components of any Bayesian analysis are the specification of the prior distributions of reliability, the loss function measuring the loss incurred by misestimating the true reliability, and the component and system test results. Because ABRAM is based on the assumption of squared error loss function (the most common form used in reliability estimation), only the first two moments of the prior distribution of reliability need be specified. That is, a complete Bayesian analysis is available from the moments of the reliability distribution because:

- the Bayesian estimate of reliability is the mean (first moment) of the distribution; and
- the expected loss (risk) is proportional to the variance (second moment minus first moment squared) of the distribution.

For simplicity and clarity, we have selected the beta family of distributions to serve as the parametric form of the prior distribution. Actually, since only the first two moments of the beta distribution are utilized, the selection of the beta was made principally to allow the user of ABRAM to specify his degree of prior belief in terms of a well-known family. The use of the beta parameters, pseudo-successes and pseudo-failures, should facilitate the specification of the first two moments on the part of the user, since (as shown in Part 3) these parameters are readily interpretable.

The test results that can be used by ABRAM may be either the complete system, the subsystem, and/or individual components. When test results are entered at other than the component level, the validity of the use of the entire beta distribution as the form of the updated prior distribution, rather than its first two moments, is in question. Nonetheless, in practice, the error introduced by fitting a beta distribution appears to be very small and well worth the convenience.

The basic objective of the analysis is to identify that component which reduces the "prior expectation of the posterior risk" of the system reliability at least cost. This value is determined by calculating both

the system risk that would occur if the component to be tested resulted in a success, and the system risk that would occur if the component to be tested resulted in a failure. These two values of risk are then weighted by the current estimate of the reliability and unreliability of the component in question and summed. This sum, representing an expected risk, is subtracted from the current value of the system risk and divided into the cost of testing the component. The resulting value is the cost of achieving a unit reduction in risk. The component which reduces the risk at least cost is then selected for the next test.

II. FRAMEWORK FOR THE COMPARISON METHODOLOGY

As mentioned earlier, no cost data from test programs were available. Therefore, we decided to employ a predetermined set of simulated test results to identify the savings that could be achieved by a cost-effective test plan. The basic approach was to select a hypothetical system and test it in a conventional manner until a pre-established test budget was exhausted. Then, the same set of test data would be called upon in a sequential test plan until the system risk was reduced to the level achieved by the conventional test plan. The cost to achieve this level of risk would then be compared to the original test budget to see what savings, if any, were achieved.

The conventional test plan was structured so that each component in the system would be tested a proportionate number of times; that is,

each component in the system would be tested even though it appeared more than once in the system. For example, for two identical components connected in parallel, twenty tests would be conducted on the component in a system tested ten times. This type of testing, as noted earlier, is commonly associated with surveillance testing for detecting degradation of component reliabilities.

The simulated test data constructed for each component were designed to reflect the system test data used in the conventional test plan. This insured that the final estimates of system reliability were not widely divergent because of an unexpected failure occurring early or late in the sequence. Moreover, both test plans started with the same prior distribution of system reliability to insure an equitable point of departure.

A question not addressed in the analysis, however, was how the estimate of system reliability resulting from both the conventional and cost effective test plans compares to the actual reliabilitv as testing progresses. Although it can be shown that the cost-effective test plan converges to the true reliability as the number of tests increases, it is not clear how the estimate behaves relative to the conventional test plan for small test numbers.

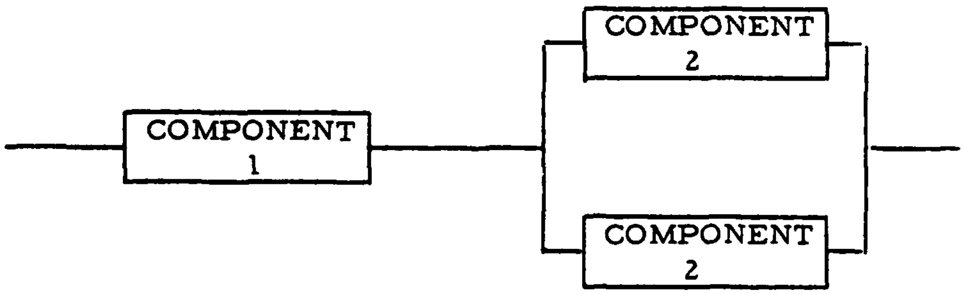
III. HYPOTHETICAL SYSTEM TO BE TESTED

Since the cost-effective test plan may be used on a variety of different systems, it appeared reasonable to evaluate the plan on the simplest system. If the benefits can be seen on the simple system, then they may be even greater for more complex systems. On the other hand, if no benefits can be seen on the simple system, the usefulness of a cost-effective test plan may be questionable.

The configuration of the hypothetical system used to compare the cost-effective test plan against the conventional test plan is shown below.

Exhibit 1

HYPOTHETICAL SYSTEM



The cost per test of each component and, therefore, of the entire system is as follows:

Component 1	$2500
Component 2	$3500
System	$9500

If, for example, \$95,000 were available for testing, the conventional test plan would test the hypothetical system ten times. On the other hand, the cost effective test plan would spend only the amount of test dollars needed to attain the level of risk achieved by the conventional test plan, presuming that it can be done for less than \$95,000.

The predetermined test results for the system were 8 successes and 2 failures. The component test results resulting from the system tests were assumed to be as follows.

Exhibit 2

CONVENTIONAL TEST PLAN

	Successes	Failures	Total Tests
Component 1	8	2	10
Component 2	20	0	20

The sequential plan used the same component test results except that all additional tests required of a component were assumed to be successes. The results of the cost effective test were as follows:

Exhibit 3

COST-EFFECTIVE TEST PLAN

	Successes	Failures	Total
Component 1	12	2	14
Component 2	2	0	2

Under both test plans (with these predetermined test results and the prior distributions listed in Exhibit 4) the final values of the system

risk were nearly identical. However, as will be shown, the cost of the 14 component tests conducted under the sequential test plan was less than half the cost of 10 complete system tests. Thus, substantial savings may be realized.

IV. THE TEST PLAN RESULTS

The conventional test plan, by construction, used the entire $95, 000 for its ten complete system tests. The prior distributions placed on the system and components during both test plans were:

Exhibit 4

QUANTITIES OF INTEREST
DERIVED FROM PRIOR DISTRIBUTIONS

Item	Bayes' Estimate of R	System Risk	(Pseudo) Successes	(Pseudo) Failures
Entire System	0.6667	0.0171	7.00	3.00
Component 1	0.8165	0.0127	7.82	0.98
Component 2	0.5716	0.0318	2.82	1.87

The risk of misestimation, based solely on prior distributions before either test plan was implemented, was 1709. This value is defined to equal 100,000 times the variance of the distribution of system reliability.

The risk, according to the conventional test plan results, was 862. Interestingly, the system risk was lower when the system test results were used to update the prior distribution of system reliability instead of the more common practice of using the component test results to

update the prior distributions of component reliabilities. Consequently, we used the system test results, which are shown in Exhibit 5 for comparison purposes, since they provided a lower risk.

Exhibit 5

QUANTITIES OF INTEREST
DERIVED FROM THE POSTERIOR DISTRIBUTIONS

Conventional Test Plan

	Bayes' Estimate of R	System Risk	(Pseudo) Successes	(Pseudo) Failures
System Reliability	0.7273	862	15.00	5.00

The goal of this demonstration is to show that a system risk of 862 can be obtained without expending the full test budget when a cost-effective plan is used for testing individual components. It will, in fact, be shown that less than half of the test budget need be spent to attain this level of risk.

The next exhibit, Exhibit 6, summarizes the output from ABRAM used to identify the cost savings. Each line of this exhibit shows the necessary information for implementing the next step of the cost effective plan. For example, the first line shows the starting position of the test program. Based solely upon prior distributions, the Bayes' risk of misestimation is 1709. The second and third columns from the right show the average costs per unit reduction in risk that are expected if a particular component is tested. For example, if component number one is tested, it is expected that the \$2500 cost will produce 72 (\$2500/34.80)

Exhibit 6

COST-EFFECTIVE TEST PLAN

Test No.	Component Tested	Success or Failure	System Risk After Testing	Cost Per Unit Reduction Component 1	Cost Per Unit Reduction Component 2	Cumulative Test Costs
0	--	-	1709	$34.80	$34.40	$0
1	2	S	1499	31.30	62.80	3500
2	1	S	1386	39.50	61.40	6000
3	1	S	1296	49.10	60.30	8500
4	1	S	1224	60.00	59.40	11,000
5	2	S	1067	56.00	103.40	14,500
6	1	F	1164	48.80	114.90	17,000
7	1	S	1090	58.00	113.10	19,500
8	1	S	1027	68.30	111.40	22,000
9	1	S	973	79.80	109.90	24,500
10	1	S	927	92.40	108.60	27,000
11	1	S	887	106.40	107.40	29,500
12	1	F	926	96.60	116.40	32,000
13	1	S	890	109.60	114.80	34,500
14	1	S	858	123.70	113.40	37,000

units of risk reduction; whereas, if component two is tested, the \$3500 cost is expected to produce 102 (\$3500/34.40) units of risk reduction. Therefore, the cost-effective test plan tests component number two first.

As shown, the first test result was predetermined to be a success. After this result is given to ABRAM, the program produces the calculations shown on the second line.

The estimate of system reliability increases because of the success and the risk decreased to 1499. However, the risk decreased by more than the 102 units expected. The difference between the expected decrease and the actual decrease occurred because of the randomness associated with the test results. ABRAM bases its calculations on the expected value of the risk reduction; sample realizations are anticipated to deviate from these expected values.

After the sixth test, for example, the risk actually increased. It increased because the Bayes' estimate indicated, before this test, that the reliability of the system was over .7, but then a failure occurred. This test result conflicts to some degree with the pretest expectations accounting for the increased risk.

After the 13th test, a level of risk nearly equal to that of the conventional test plan was reached (890 as compared to 862). However, the cost-effective plan required only \$34,500 of the \$95,000 test budget. Since the stated goal of this demonstration was to attain at least as low a risk

using the cost-effective plan as achieved by the conventional plan, one more test was conducted. The first component was tested again in the fourteenth test, since it was cost-effective to do so, and the test was predetermined to be a success. The total cost, then, was $37,500, a 61% reduction from $95,000.

V. CONCLUSIONS

The substantial savings that were achieved in the system in Exhibit 1 resulted, in part, from components connected in a parallel. A complete system test is wasteful, in this case, because less information is needed to be precise about the second serial subsystem, which consists of the two parallel components. Hence, when there are subsystems with components in parallel, the cost-effective test plan should produce reliability assessment information at less cost.

Another advantage of the cost-effective test plan is that it takes into account the cost differentials involved in testing different components. Two (approximately) equally reliable but different components may provide nearly the same test information about the system reliability. However, it makes sense to test one of the components more than the other if test budgets are constrained. The cost-effective test plan does this, but the conventional test plan does not.

Several qualifications should be made concerning the preceding statements. First, the example is only that--an example. The savings of 61% can not be anticipated in every situation. Second,

individual component tests do not provide information about the workmanship connecting the different components. If there is realistic concern about the dependency among component reliabilities, then some complete systems or subsystems tests should be conducted. Third, a more practical test plan would test more than one individual component at a time. It is not realistic, for example, to expect tests to be conducted one at a time, awaiting the results of a previous test. Fourth, the methodology currently does not consider fixed set-up costs for testing. If a test facility has to be rented, for example, a particular component may have a high set-up cost. Finally, it should be noted that since test results are random and the cost effective test plan uses these results in a sequential manner, there is always a chance that the cost-effective plan will actually reduce the risk less than the conventional plan. However, this should be a rare occurrence if the number of tests conducted is large.

In sum, this short exercise has raised almost as many questions as it has answered. A true test of the methodology will require taking an actual system using actual test and cost data, and determining the savings that are possible. We would not be surprised, however, to find that these savings are substantial.

PART 3

USER'S MANUAL

AUTOMATED BAYESIAN RELIABILITY ASSESSMENT MODEL (ABRAM)

PART 3

USER'S MANUAL

AUTOMATED BAYESIAN RELIABILITY ASSESSMENT MODEL (ABRAM)

ABRAM is a general purpose FORTRAN IV computer software program which provides a technical or nontechnical user the capability to employ Bayesian reliability assessment techniques in assessing the reliability of multi-component systems. ABRAM has several features which distinguish it from traditional/classical reliability assessment programs:

- The user need not know how to construct a mathematical model which relates the reliabilities of the components of a multi-component system to the reliability of the system. ABRAM generates the mathematical model internally.

- ABRAM allows the user to specify prior distributions of reliability at the system level, the subsystem level, the component level, or at all three levels. Consistency in selection of prior distributions is assured by the program.

- ABRAM permits the combination of system test results and component test results in the same assessment. This feature allows the user to apply all the data on a particular system to determine estimates of reliability.

- An optimal sequential testing methodology is programmed into ABRAM. This feature allows the user to obtain test data at the most cost-effective rate to acquire knowledge of the reliability of the system.

Thus, ABRAM is a state-of-the-art computer program which provides a number of options to the user in employing Bayesian reliability assessment techniques. The purpose of this manual is to provide instructions necessary to use the program.

The manual is organized into six sections:

- Review of the Bayesian Approach to Reliability Assessment
- Instructions for Coding the Component Configuration in the System
- Guidelines for Specifying Prior Distributions of Reliability
- Instructions for Formatting Input Data
- Interpretation of the Output of ABRAM
- Listing of Program Code of ABRAM

I. REVIEW OF BAYESIAN APPROACH TO RELIABILITY ASSESSMENT

The Bayesian approach to statistical estimation is based on the notion that probability can be interpreted as the degree of belief in an event, as opposed to the frequency with which an event occurs. In the case of reliability assessment, the event is defined as the successful operation of the system or component. Although the component or system may have a fixed reliability (or probability of success), the value of the particular reliability is unknown to the analyst. The analyst, however, may have incomplete knowledge about the reliability of a particular component or of the system which he desires to express in a formal way.

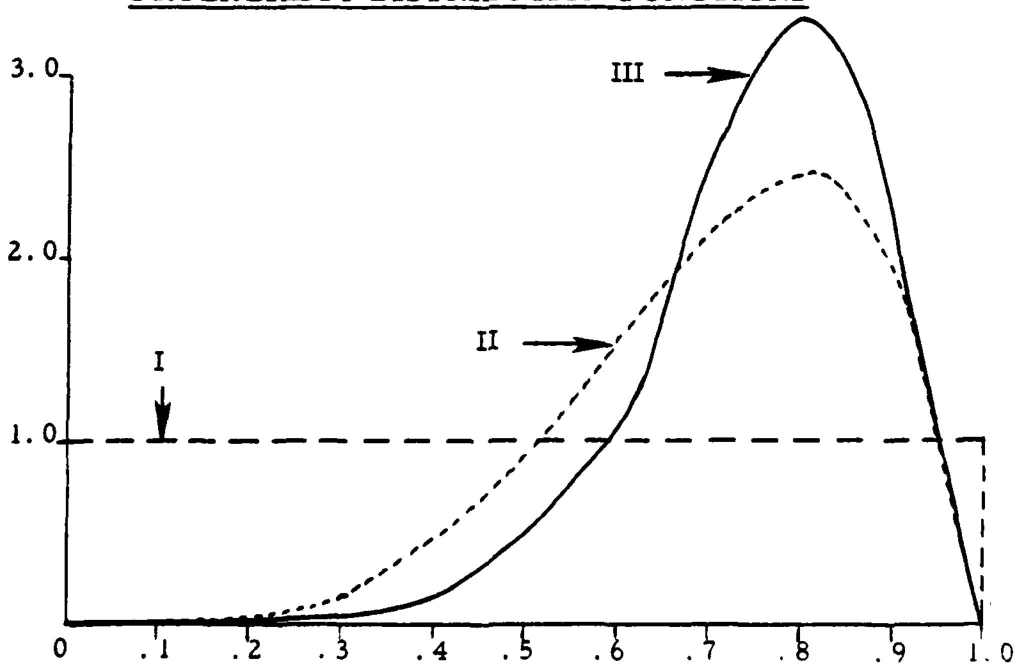
The analyst using the Bayesian approach specifies his degree of belief that the reliability of the system or component takes on specific values between zero and one. The mechanism that is used to describe this degree of belief is a probability density function which defines the probability (subjective) that the true reliability of the component or system falls in a particular interval of reliability values. Thus, the Bayesian approach

incorporates in a formal way the analyst's pretest opinions about the component and system reliabilities.

The following exhibit illustrates three different probability density functions of reliability. The <u>uniform</u> distribution, labeled I, may be considered neutral, in that every reliability is perceived as being equally likely before test results are observed. That is, the analyst does not believe that he knows enough to favor any particular interval of reliability over any other interval. The second distribution, labeled II, suggests more information, because the analyst is expressing that the true value of reliability is believed to be between .50 and .90. The distribution labeled III provides the most information, because it reflects the analyst's belief that the true reliability is between .70 and .90.

Exhibit 1

PROBABILITY DISTRIBUTION FUNCTIONS



The form of the prior distribution of reliability can be specified parametrically when the beta family of distribution is used with two parameters termed pseudo-successes and pseudo-failures. The prefix pseudo is used because the values are not really successes and failures; however, the parameters of the distribution change exactly as if the same number of successes and failures were observed as test results. Hence, the values of the parameters are commonly interpreted as pseudo-successes and pseudo-failures.

The following exhibit shows the parameters of the three density functions.

Exhibit 2

PARAMETERS OF DENSITY FUNCTIONS

Density Function	A Pseudo-Successes	B Pseudo-Failures
I	0	0
II	4	1
III	8	2

The functional form of the density function is as follows:

$$f(R) = K * R^{A} * (1-R)^{B} \quad ,$$

where K is a constant, A the number of pseudo-successes, and B, the number of pseudo-failures

The attractive feature of the beta family of distributions, when used as prior distributions for pass-fail testing, is that when test results are obtained, they can simply be added to the number of pseudo-successes and pseudo-failures to obtain the revised distribution of degree of belief. For example, the distribution III would also be the posterior distribution of reliability had the analyst started with the initial (or prior) distribution I and then observed 8 successes and 2 failures as test results.

In assessing the reliability of a multi-component system, the analyst's degree of belief about the reliability of each component and the system must be specified either by the analyst or by ABRAM. That is, a prior distribution of reliability must be specified for the system and/or each component. ABRAM assigns a uniform distribution as the prior distribution of the system, unless the analyst specifies otherwise. Prior distributions for component reliabilities that are not specified are assigned by ABRAM subroutines, which allocate uncertainty, as measured by the variance of the distribution, evenly over all components.

It should be noted that, in general, the parameters pseudo-successes and pseudo-failures need not be integer valued, as must the test results describing successes and failures. Moreover, these parameter values can be negative as long as they are greater than minus one; for example, values of A and B of -.99 are permissable. The lower the values of A and B, the easier it will be for test results to mask or overpower the original selection of A and B. Thus, if A and B are initially 0.5 and 0.0, say,

the posterior distribution that would result after 10 successful tests would be 10.5 and 1.0. Thus, the test results are much more important than the prior specification of the distribution. If high values of A and B are chosen to characterize the prior distribution of reliability, it will be more difficult for the test results to "wash out" the implications of the prior specification.

The Bayesian approach also consists of assigning a loss that will result if the true reliability is misestimated. The most commonly assumed form of the loss function is the squared error loss function. Thus, if R is the true reliability and $\hat{R}$ is the estimate, the loss is proportional to $(\hat{R}-R)^2$. The risk is defined as the expected loss and is calculated using the probability distribution function of reliability.

$$\text{RISK} = \int_0^1 f(R)\,(\hat{R}-R)^2\,dR.$$

The Bayes' estimate of reliability is the one that minimizes the risk. For a squared error loss function, the Bayes' estimate is the mean of the distribution and the risk is directly proportional to the variance of the distribution. The first two moments of any distribution, then, provide the necessary information for a complete Bayesian assessment. From this information the risk can be computed. ABRAM takes advantage of these technical facts and works only with the first two moments of each distribution in developing estimates of system reliability.

II. INSTRUCTIONS FOR CODING COMPONENTS

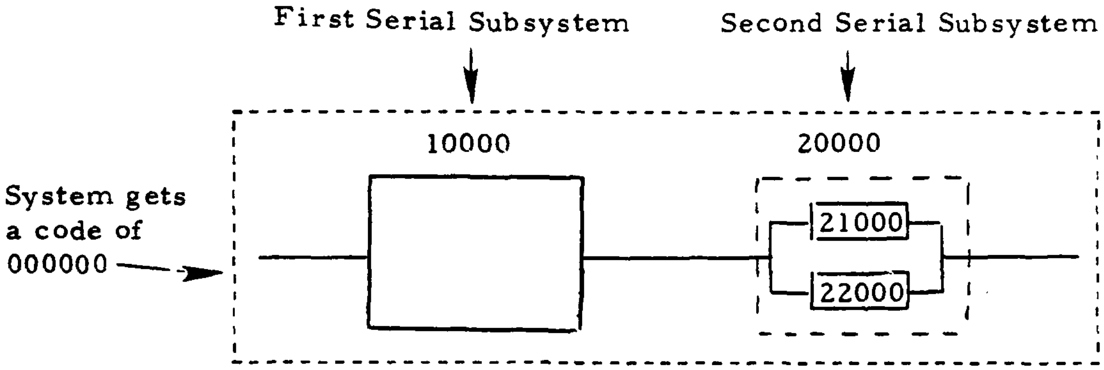
Because of the complexity of the calculations involved in computing prior and posterior distributions of component and system reliabilities, we have developed an automatic math model generator as one of the subroutines of ABRAM. This subroutine will construct a model of the system if the input data are coded according to the scheme described in this section. Thus, the analyst does not have to input a complex equation relating component reliabilities to the system reliability. Before graphically illustrating the code, we give a brief description.

The position of each component in the system is represented by a five-digit code. The first digit from the left identifies the serial subsystem to which the component belongs. That is, all components belonging to the first subsystem, for example, have codes in the 10000 series. The second digit identifies the parallel path of the serial subsystem to which the component belongs. The third digit identifies the serial group of the parallel path. The fourth identifies the parallel subpath of the serial group, and the fifth the serial subgroup of the parallel subpath. If the digit is zero, then no such serial or parallel subgroup component exists.

For example, consider the following system:

Exhibit 3

SERIAL SUBSYSTEMS

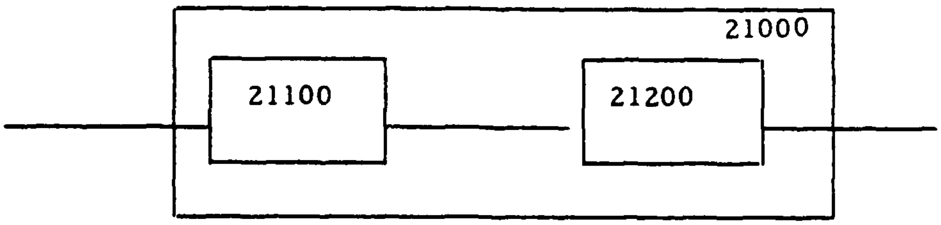


The code 10000 refers to the first subsystem; the code 20000 refers to the second subsystem. The two parallel paths in the second subsystem are denoted 21000 and 22000.

Assume that the first parallel path of the second subsystem is composed of additional groups of components in series as shown below.

Exhibit 4

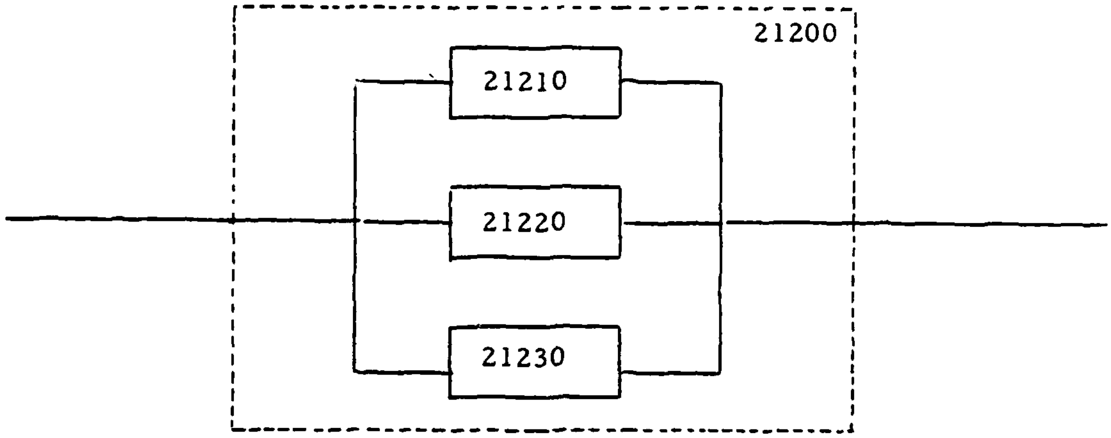
PARALLEL PATH



These serial groups would be coded 21100 and 21200 to designate their position in the system. Suppose further that the second serial group in 21000, which we call 21200, had three parallel subpaths as follows:

Exhibit 5

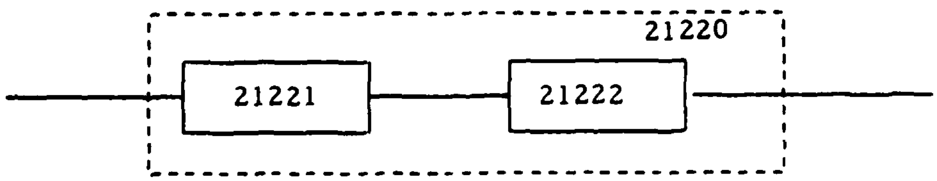
PARALLEL SUBPATHS



These would be coded as 21210, 21220, and 21230. Finally, assume that the second parallel subpath in 21200, which we call 21220, has two serial components as shown below.

Exhibit 6

SERIAL COMPONENTS



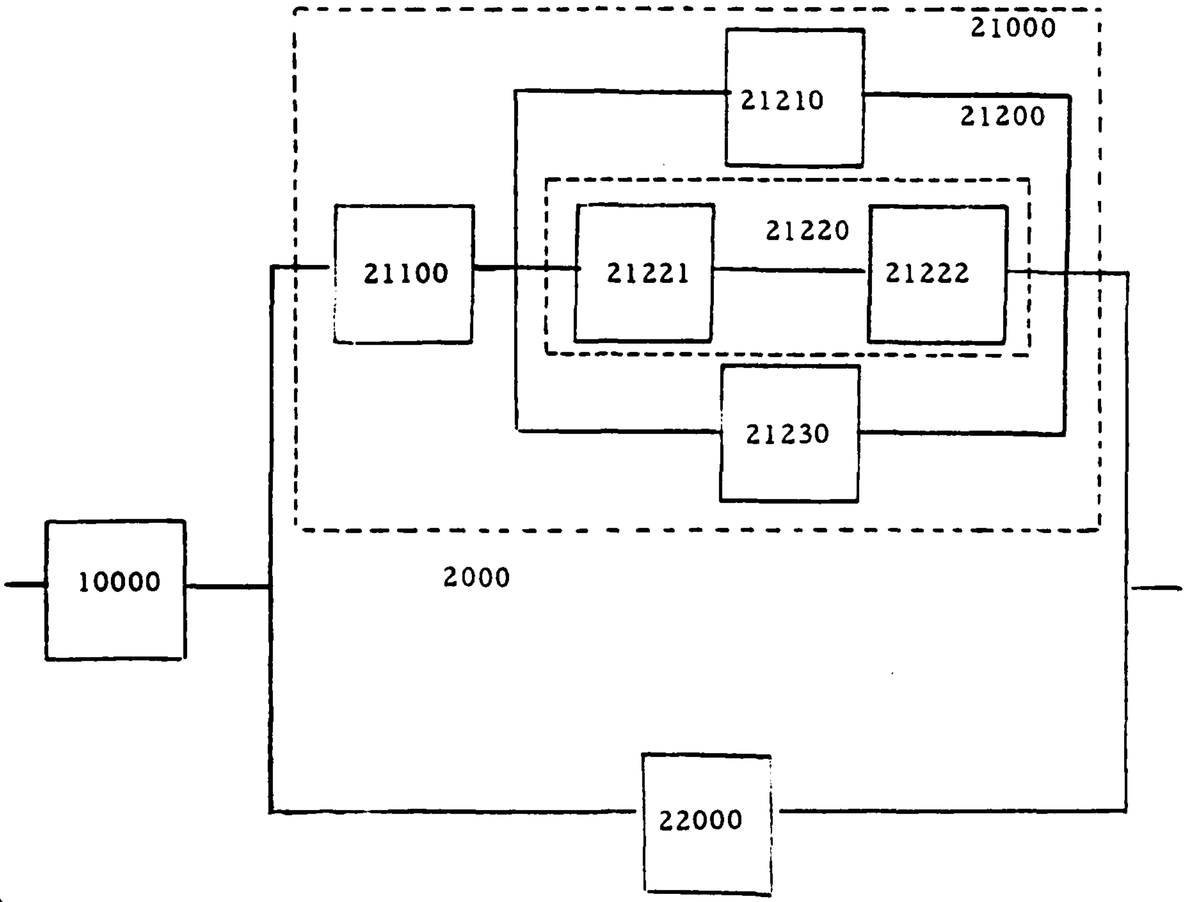
As can be seen, these are coded with the last digit.

In summary, the hypothetical system described would appear as shown below. Note that each component has a code which identifies:

- the serial subsystem;
- the parallel path of the subsystem;
- the serial group of the parallel path;
- the parallel subpath of the serial group;
- the serial subgroup of the parallel subpath.

Exhibit 7

TOTAL SYSTEM



Thus, any system with five levels of complexity can be described by the five-digit code.

In coding these components, all higher level codes should also be present. For example, although a single component comprises the first serial subsystem (code 10000), several components comprise the second serial subsystem. Although the code 20000 does not appear explicitly, the analyst should specify it for completeness. However, ABRAM will provide the higher level codes if they are not specified.

The following exhibit shows the input codes for the system just described.

Exhibit 8

HYPOTHETICAL SYSTEM CODES & COMPONENTS

I	Code	Component Number
1	00000	*
2	10000	1
3	20000	*
4	21000	*
5	21100	2
6	21200	*
7	21210	3
8	21220	*
9	21221	4
10	21222	5
11	21230	3+
12	22000	6

* Signifies that the code does not refer to an actual component, but to an aggregation of components.

+ This component is assumed to be identical to the component coded by 21210 and, therefore, its reliability will be the same.

The code 00000 refers to the entire system and must always be present. Because only one digit is currently allowed to reference each level, up to 9 serial subsystems can be accommodated.

III. GUIDELINES FOR SPECIFYING A PRIOR DISTRIBUTION OF RELIABILITY

This section of the manual is organized into three parts:

- specifying prior distributions at the component, subsystem, or system level;
- some ideas for specifying a prior distribution when dealing with an independent contractor;
- some ideas for helping to specify a prior distribution for internal use.

A. SPECIFYING PRIOR DISTRIBUTIONS AT THE COMPONENT, SUBSYSTEM, OR SYSTEM LEVEL

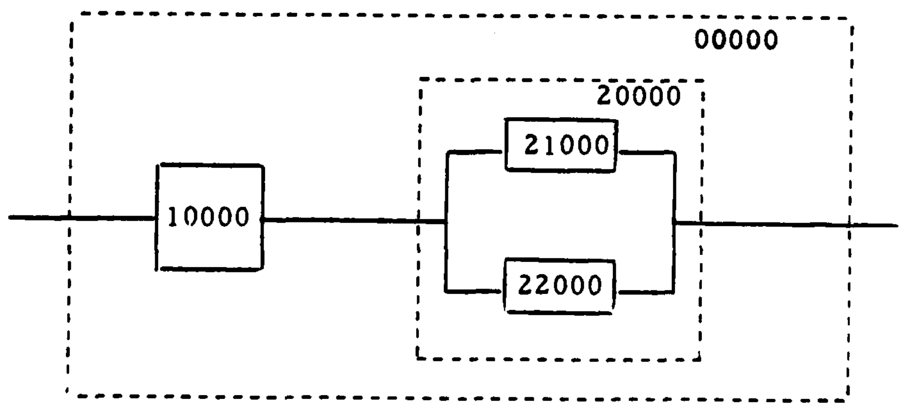
Taking full advantage of prior knowledge about the component, subsystem, and system reliabilities enables the analyst to make decisions with the least risk. Therefore, it should be helpful to specify a prior distribution for each component, subsystem, and system where there is prior knowledge. The level in the system where these prior distributions are specified should take into consideration the importance of these levels in the analysis. For example, if a decision is to be made on accepting a system from a contractor, it may be useful to consider placing a uniform prior distribution on the system reliability. If, on the other hand, a decision is to be made about accepting a few components from a contractor, it may be useful to consider placing a uniform prior distribution on these

components. When the responsibility for accepting various levels of the system is delegated to different individuals or organizations, a group consensus might be required on what prior to select. We have no firm recommendations for resolving different organizational viewpoints except that agreement on the prior distribution of system reliability is obviously the most important.

A special feature of ABRAM is that it will generate prior distributions for the components or subsystems of the system that the analyst does not specify. Since mathematical rules governing the system operation do not allow completely free choice of prior distributions, ABRAM will generate the necessary priors consistent with every mathematical rule. This is a useful feature if the analyst chooses not to specify a complete set of prior distributions. For example, consider the following system:

Exhibit 9

HYPOTHETICAL SYSTEM



Suppose prior distributions are specified for the system (00000), the first serial subsystem (10000), and the first component of the second serial subsystem (21000). Then ABRAM automatically assigns the appropriate prior for the second serial subsystem (20000) and its second component (22000). The output listing of ABRAM provides the parameters of the prior distributions internally assigned so the analyst can check them for reasonableness.

B. SOME IDEAS FOR SPECIFYING A PRIOR DISTRIBUTION WHEN DEALING WITH AN INDEPENDENT CONTRACTOR

The best procedure is to assign prior distributions which reflect actual knowledge about the reliability of the system and its components. In this way less risk will result after testing the system. However, if an outside contractor is involved, a consensus should be reached about the prior distribution of the reliability of the system. It may be in the government's best interest not to let the contractor choose the prior distribution at the system level. After all, the contractor has a vested interest in demonstrating the high reliability of his system. In such cases, it would be safe to place a uniform prior on the system (or the highest level of the system with which the contractor has a direct connection). This allows the test data to have an effect in the analysis. When several different contractors are making components for the system, and different DoD offices have responsibility for deciding whether or not to accept them, each office should makes its own decisions about prior specification.

When only one analyst is deciding whether or not to accept the contractor's components, the following rule of thumb may be useful. The data will have significant impact on the systems analysis if the uniform prior is placed on the system, a moderate impact if the uniform prior is placed on each subsystem, and the least impact if the uniform prior is placed on all the components. In the latter two cases, incidentally, the system prior will be skewed toward zero.

C. SOME GUIDELINES FOR SPECIFYING PRIOR DISTRIBUTIONS FOR INTERNAL USE

The key point for the analyst to consider in choosing a prior distribution is the sensitivity of the posterior assessment to the test results.

If there are recent data available about the reliability of the system and components, they can be used to specify the prior distribution. ABRAM will accept the given number of successes, A, and failures, B, of the system, subsystem, and components as prior specifications and compute a consistent set of prior distributions for the remaining components and subsystems.

When there is not recent data available, the analyst may specify his prior opinions in terms of pseudo-successes, A, and pseudo-failures, B, which reflect his degree of belief about the reliability. The following rules of thumb may be helpful in specifying a prior distribution:

- When the analyst is reasonably convinced about what the component, subsystem, or system reliabilities are, he

might specify his prior by choosing A + B = 20 and(A/20) equal to his best point estimate of the component and system reliabilities. This specification reduces the impact of any future test results on the analysis. For example, if he is reasonably certain the reliability is 0.8, he may set A = 16 and B = 4. (Again, it may be useful to recall that the system prior distribution is the most important to specify.)

- When the analyst has some idea about what the component, subsystem, or system reliabilities are, he might specify his prior distribution by setting A + B = 5 and (A/5) equal to his best point estimate of the reliability. This choice of prior distribution will give the data a moderate impact on the analysis. For example, if he is moderately certain that the reliability is .8, he might set A = 4 and B = 1.
- When the analyst is not at all certain about what the system and component reliabilities are, he might specify a uniform prior distribution for the system by setting A = 0, B = 0. This specification will give future test results a great impact in the analysis.

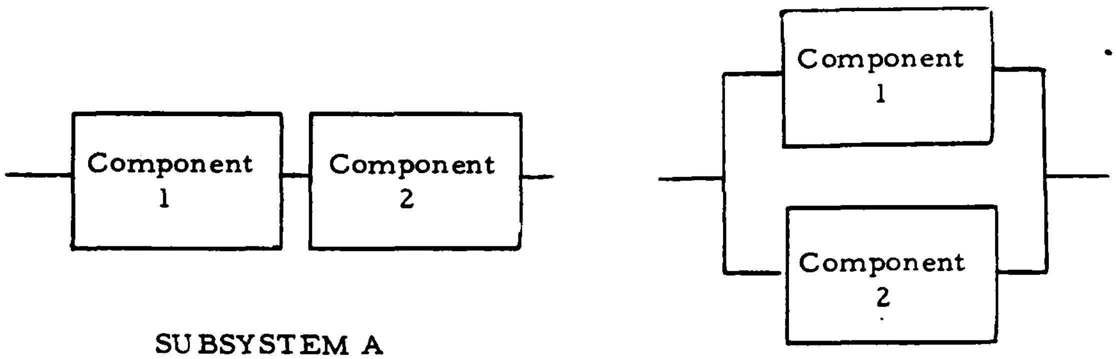
Regardless of how the prior distributions are specified, certain assignment rules must be followed or ABRAM will print the error message: "Component and System Priors are Inconsistent." These rules are that all serial subsystems must be less reliable than any of their serial components and all parallel subsystems must be more reliable than any of

their components. Moreover, the variance of any distribution must be greater than zero.

For example, consider the following two subsystems.

Exhibit 10

SUBSYSTEM EXAMPLES



SUBSYSTEM A

SUBSYSTEM B

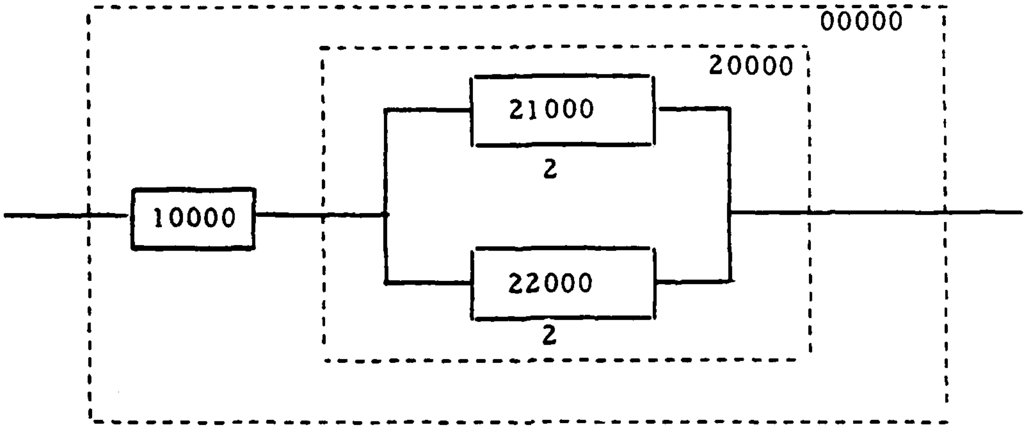
If the first (or second) moment of the prior distribution of the reliability of subsystem A is greater than the first (or second) moment of the prior distributions of components one or two, ABRAM will print the error message. If the moments of the prior distribution of the reliability of subsystem B are less than either of the moments of the prior distributions of the reliabilities of components one or two, ABRAM will print the error message. If the variance of any component or system distribution is negative, ABRAM will print the error message.

IV. INSTRUCTIONS FOR FORMATTING INPUT DATA

The procedure for formatting input data for ABRAM will be explained using the following system:

Exhibit 11

SYSTEM EXAMPLE



COST OF TESTING: Component 1 = $250; Component 2 = $350

This section presents the steps that should be used to utilize ABRAM effectively. Three exhibits are presented: Exhibit 12 shows the proper input format for ABRAM, and Exhibits 13 and 14 show the proper input format for the hypothetical system in Exhibit 11 above.

STEP 1: SPECIFY THE MODE IN WHICH ABRAM IS TO WORK

Since analyzing test data to compute estimates of reliability does not require calculating a cost-effective test plan, ABRAM can operate in two modes. The choice of modes allows ABRAM to be used most efficiently.

Exhibit 12

ABRAM'S INPUT FORMAT

INPUT DATA FOR PROGRAM

MODE - 0 FOR SEQUENTIAL MODE, 1 FOR SIMULTANEOUS MODE

MAX - NUMBER OF CONFIGURATION CODE ENTRIES

ICMAX - NUMBER OF DISTINCT COMPONENTS

IC(I) - CONFIGURATION CODE FOR ENTRY I

ICN(I) - COMPONENT NUMBER FOR ENTRY I

ICOST(I) - COST OF TESTING THE COMPONENT ENTRY I

NUMPRI - NUMBER OF PRIOR DISTRIBUTIONS TO BE SPECIFIED

IA(J) - PSEUDO SUCCESSES FOR JTH COMPONENT

IB(J) - PSEUDO FAILURES FOR JTH COMPONENT

NUMCOM (SIMULATENOUS MODE ONLY) - NUMBER OF COMPONENTS WHICH HAVE BEEN TESTED

STOP (SEQUENTIAL MODE ONLY) - 000000

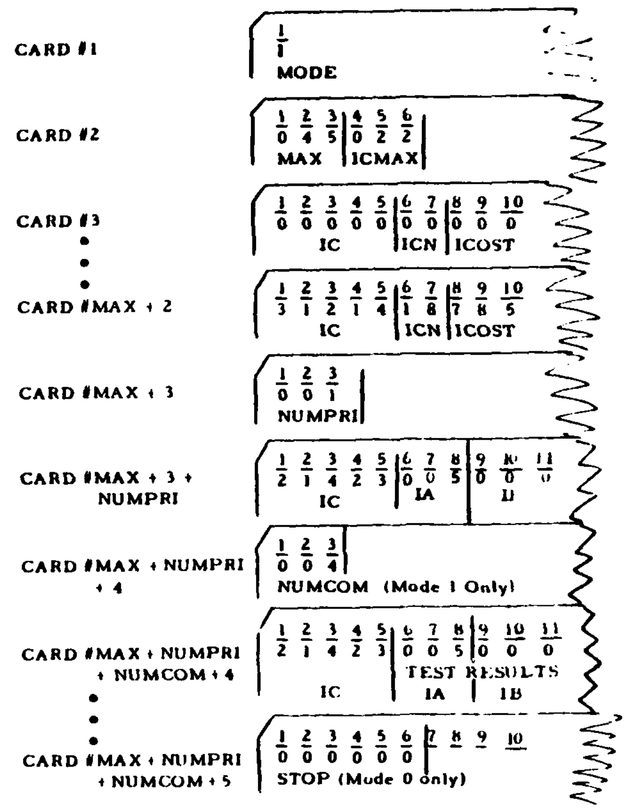


Exhibit 13

CORRECT INPUT DATA FORMAT - SIMULTANEOUS MODE

Card	Code
1.	1
2.	005002
3.	0000000000
4.	1000001250
5.	2000000000
6.	2100002350
7.	2200002350
8.	02
9.	00000007002
10.	10000005000
11.	02
12.	01007000
13.	02008001

Exhibit 14

CORRECT INPUT DATA FORMAT - SEQUENTIAL MODE

Card	Code
1.	0
2.	005002
3.	0000000000
4.	1000001250
5.	2000000000
6.	2100002350
7.	2200002350
8.	02
9.	00000007002
10.	10000005000
11.	01007000
12.	02008001
13.	000000

ABRAM can aid in finding both the best sequential test plan and the Bayes' estimates of system, subsystem, and component reliabilities.

- The simultaneous mode provides the usual and necessary statistical analysis for estimating the reliabilities without calculating a cost-effective test plan. This is the traditional analysis that is performed after all testing is completed and the results are available. The simultaneous mode is specified by MODE = 1.
- The sequential mode provides a cost-effective test plan developed sequentially, as well as the same statistical capabilities as the simultaneous mode. The sequential mode is specified by MODE = 0.

STEP 2: SPECIFY BOTH THE NUMBER OF CONFIGURATION CODES AND THE NUMBER OF DISTINCT COMPONENTS

After ABRAM is given the mode specification, it will generate a math model for the system. In order to do this effectively, it must be supplied with the proper configuration codes and component numbers as described in Section II. ABRAM reads exactly the number of configuration codes specified by MAX. For the system in Exhibit 11, MAX = 5.

In addition, ABRAM sets up a model having the number of distinct components = ICMAX. Since there are only two distinct components of the system in Exhibit 11 (the one component comprising the first serial subsystem and the two identical components comprising the second serial subsystem) ICMAX = 2.

STEP 3: SPECIFY THE COMPONENT CONFIGURATION CODES, COMPONENT NUMBER, AND COST OF TESTING EACH COMPONENT

ABRAM generates the proper math model having at least the number of subsystems specified by Step 2. The component configuration codes indicate where each component is located, and the component identification numbers indicate which components are distinct. Thus, the identical components will have different configuration codes but the sample component identification number. (Note that identical components should have identical prior distributions also.) In the sequential mode, Mode 0, ABRAM finds the cost-effective test plan using the inputted amount that it costs to test each component.

For the system shown in Exhibit 11, the codes will be:

Exhibit 15

COMPLETE SET OF CODES

IC Configuration Codes	ICN Component Number	ICOST Cost of Testing
00000	0	0
10000	1	250
20000	0	0
21000	2	350
22000	2	350

(The system and subsystems which have more than one component are given the component number 0.)

ABRAM will generate the correct math model even if it is only given the following codes:

Exhibit 16

REDUCED SET OF CODES

IC Configuration Codes	ICN Component Number	ICOST Cost of Testing
10000	1	250
21000	2	350
22000	2	350

However, ABRAM allows user-specified prior distributions only for user-specified configuration codes. Thus, the greatest benefit from ABRAM can be obtained by specifying all the configuration codes.

STEP 4: SPECIFY THE NUMBER OF PRIOR DISTRIBUTIONS

The prior distributions can be specified for the system, subsystem, and component reliabilities using the configuration codes. NUMPRI = number of prior distributions to be specified. For each prior distribution, the user must also specify the configuration code and the pseudo-successes and the pseudo-failures as shown in cards 8, 9, and 10 of Exhibit 13.

Full advantage of knowledge of the system's, subsystem's, and components' recent reliability performance can be obtained by specifying prior distributions according to the guidance provided in Section III of this Manual.

STEP 5: (SIMULTANEOUS MODE ONLY): SPECIFY THE NUMBER OF COMPONENTS WITH RECENT AVAILABLE TEST DATA

After ABRAM has received the user-specified prior distributions, it will accept only component test results. Test data for the system and subsystems are included in the prior specification by letting IA = the number of pseudo-successes plus the number of actual test successes and IB = the number of pseudo-failures plus the number of actual test failures. If test results are available on two components of the system, then NUMCOM = 2. For the hypothetical system, assume these results are:

Exhibit 17

HYPOTHETICAL TEST RESULTS

Component	Successes	Failures
1	7	0
2	8	0

These results are shown in cards 11 and 12 of Exhibit 13.

STEP 6: (SEQUENTIAL MODE ONLY) - SPECIFY THE TEST RESULTS

After ABRAM has received the user-specified prior distribution, it will look for test results of the next component tested.

Assume the recent test results obtained in sequential manner for the system in Exhibit 1 are as follows:

Exhibit 18

SEQUENTIAL TEST RESULTS*

Component	Successes	Failures
1	7	0
2	8	0

*more than one test of each component was conducted.

They should be given to ABRAM in the format shown in cards 11 and 12 of Exhibit 14. Inputting a blank card will stop the testing.

V. INTERPRETATION OF OUTPUT LISTING OF ABRAM

In order to understand the output from ABRAM, it should be helpful to study the two printouts at the end of this section. They are ABRAM's response to the simultaneous mode input of Exhibit 13 and the sequential mode input of Exhibit 14.

The first table of output from ABRAM is the EDITED INPUT which consists of the analyst's input information and some information generated internally by ABRAM.

The REFERENCE INDEX is an internally generated code that gives each component, subsystem, and system a numerical name. ABRAM uses this name to communicate to the analyst which item in the system is being addressed. These names are listed in a logical order; consecutive system components have consecutive names.

The CONFIGURATION CODE is the five-digit code described in Section III that may have been provided as input. If a subsystem code was not provided as input, ABRAM generates it in its logical position.

The COMPONENT NUMBER LIST gives the listing of identical components that was provided by the analyst as input. ABRAM assigns the component number 0 to the system and all subsystems not composed of a single component.

The COST OF TESTING gives the cost of testing each component provided by the analyst as input. Since ABRAM does not suggest testing

subsystems that contain more than one component, it lists their costs as zero.

The next table that ABRAM lists is the SPECIFICATION OF PRIOR DISTRIBUTIONS AND/OR SYSTEM/SUBSYSTEM TEST RESULTS. Using the REFERENCE INDEX described above, this table gives the user-specified prior distributions. In addition, it gives the

BEST ESTIMATE OF R - the mean of the prior distribution of system reliability, or the Bayes estimate of reliability.

VARIANCE OF R - the risk associated with the Bayes estimate of reliability, or the variance of the prior distribution of system reliability.

The next table, ESTIMATES OF RELIABILITY DERIVED FROM PRIOR DISTRIBUTIONS, gives the same information as the last table <u>except</u> that it includes the system and subsystems for which ABRAM generated a prior distribution.

The next table (found only when ABRAM is run in the <u>sequential mode</u>) gives the CURRENT RISK and the CURRENT RISK CALCULATIONS.

The CURRENT RISK is a 10^6 multiple of the system risk (or the VARIANCE OF R for the system). It is based upon the prior distributions listed in the last table and all the test results previously listed.

The CURRENT RISK CALCULATIONS gives for each component the new system risk if the component is tested and the test is a success (SYSTEM RISK IF SUCCESS), and the new system risk if the component's test is a failure (SYSTEM RISK IF FAILURE). ABRAM bases its

calculations on the expected system risk incurred by testing each component (EXPECTED SYSTEM RISK IF TESTED). The cost-effective test plan identifies the component that produces the greatest reduction in the system risk per dollar spent (or COST OF TESTING/CHANGE FROM CURRENT RISK = COST PER UNIT CHANGE IN RISK).

The next table that ABRAM gives are the component test results. (In the sequential mode, Mode 0, they are given one at a time.) They were provided to ABRAM as input.

The last table, ESTIMATES OF RELIABILITY DERIVED FROM POSTERIOR DISTRIBUTIONS, provides the standard Bayesian statistical reliability analysis. The prior distributions (both provided as input or internally generated) are combined with the test results to provide this information. Each entry in this table has the same interpretation as the entries in the table for prior distributions <u>except</u> that these entries are based on test result data and prior distributions.

Exhibit 19

OUTPUT FROM MODE 1

AUTOMATED BAYESIAN RELIABILITY ASSESSMENT MODEL

EDITED INPUT DATA

REFERENCE INDEX	CONFIGURATION CODE	COMPONENT NUMBER	COST ($) OF TESTING
1	0	0	0
2	10000	1	250
3	20000	0	0
4	21000	2	350
5	22000	2	350

SPECIFICATION OF PRIOR DISTRIBUTIONS AND/OR

SYSTEM/SUBSYSTEM TEST RESULTS

REFERENCE INDEX	BEST ESTIMATE OF R	VARIANCE OF R	(PSEUDO) SUCCESSES	(PSEUDO) FAILURES
1	0.7273	0.0165	7.00	2.00
2	0.8571	0.0153	5.00	0.0

ESTIMATES OF RELIABILITY DERIVED FROM PRIOR DISTRIBUTIONS

REFERENCE INDEX	BEST ESTIMATE OF R	VARIANCE OF R	(PSEUDO) SUCCESSES	(PSEUDO) FAILURES
1	0.7273	0.0165	7.00	2.00
2	0.8571	0.0153	5.00	0.00
3	0.8485	0.0073	13.00	1.50
4	0.6108	0.0226	4.82	2.71
5	0.6108	0.0226	4.82	2.71

Exhibit 19

OUTPUT FROM MODE 1
(Continued)

COMPONENT TEST RESULTS

COMPONENT	SUCCESSES	FAILURES
1	7.	0.
2	8.	1.

ESTIMATES OF RELIABILITY DERIVED FROM POSTERIOR DISTRIBUTIONS

REFERENCE INDEX	BEST ESTIMATE OF R	VARIANCE OF R	(PSEUDO) SUCCESSES	(PSEUDO) FAILURES
1	0.8686	0.0050	17.82	1.85
2	0.9286	0.0044	12.00	0.00
3	0.9354	0.0013	40.00	1.83
4	0.7458	0.0097	12.82	3.71
5	0.7458	0.0097	12.82	3.71

Exhibit 20

OUTPUT FROM MODE 0

AUTOMATED BAYESIAN RELIABILITY ASSESSMENT MODEL

EDITED INPUT DATA

REFERENCE INDEX	CONFIGURATION CODE	COMPONENT NUMBER	COST ($) OF TESTING
1	0	0	0
2	10000	1	250
3	20000	0	0
4	21000	2	350
5	22000	2	350

SPECIFICATION OF PRIOR DISTRIBUTIONS AND/OR

SYSTEM/SUBSYSTEM TEST RESULTS

REFERENCE INDEX	BEST ESTIMATE OF R	VARIANCE OF R	(PSEUDO) SUCCESSES	(PSEUDO) FAILURES
1	0.7273	0.0165	7.00	2.00
2	0.8571	0.0153	5.00	0.0

ESTIMATES OF RELIABILITY DERIVED FROM PRIOR DISTRIBUTIONS

REFERENCE INDEX	BEST ESTIMATE OF R	VARIANCE OF R	(PSEUDO) SUCCESSES	(PSEUDO) FAILURES
1	0.7273	0.0165	7.00	2.00
2	0.8571	0.0153	5.00	0.00
3	0.8485	0.0073	13.00	1.50
4	0.6108	0.0226	4.82	2.71
5	0.6108	0.0226	4.82	2.71

Exhibit 20

OUTPUT FROM MODE 0
(Continued)

THE CURRENT RISK IS 1653.

COMPONENT NUMBER	SYSTEM RISK IF SUCCESS	SYSTEM RISK IF FAILURE	EXPECTED SYSTEM RISK IF TESTED	CHANGE FROM CURRENT RISK	COST ($) PER UNIT CHANGE IN RISK
1	1446.28	1928.37	1515.15	137.74	1.81
2	1571.82	1656.88	1604.93	47.96	7.30

COMPONENT= 2 SUCCESSES= 0. FAILURES= 0.

THE CURRENT RISK IS 1653.

COMPONENT NUMBER	SYSTEM RISK IF SUCCESS	SYSTEM RISK IF FAILURE	EXPECTED SYSTEM RISK IF TESTED	CHANGE FROM CURRENT RISK	COST ($) PER UNIT CHANGE IN RISK
1	1446.28	1928.37	1515.15	137.74	1.81
2	1571.82	1656.88	1604.93	47.96	7.30

COMPONENT= 1 SUCCESSES= 7. FAILURES= 0.

THE CURRENT RISK IS 955.

COMPONENT NUMBER	SYSTEM RISK IF SUCCESS	SYSTEM RISK IF FAILURE	EXPECTED SYSTEM RISK IF TESTED	CHANGE FROM CURRENT RISK	COST ($) PER UNIT CHANGE IN RISK
1	922.76	1077.03	933.78	21.22	11.78
2	798.66	1065.64	902.58	52.42	6.68

COMPONENT= 2 SUCCESSES= 8. FAILURES= 1.

THE CURRENT RISK IS 504.

COMPONENT NUMBER	SYSTEM RISK IF SUCCESS	SYSTEM RISK IF FAILURE	EXPECTED SYSTEM RISK IF TESTED	CHANGE FROM CURRENT RISK	COST ($) PER UNIT CHANGE IN RISK
1	458.23	734.15	477.94	25.79	9.69
2	488.97	527.88	498.86	4.87	71.90

ESTIMATES OF RELIABILITY DERIVED FROM POSTERIOR DISTRIBUTIONS

REFERENCE INDEX	BEST ESTIMATE OF R	VARIANCE OF R	(PSEUDO) SUCCESSES	(PSEUDO) FAILURES
1	0.8686	0.0050	17.82	1.85
2	0.9286	0.0044	12.00	0.00
3	0.9354	0.0013	40.00	1.83
4	0.7458	0.0097	12.82	3.71
5	0.7458	0.0097	12.82	3.71

VI. LISTING OF PROGRAM CODE OF ABRAM

```
        DOUBLE PRECISION R1,R2,A,B
        COMMON R1(100),R2(100),IC(100),ICN(100),ICOST(100),
       1IMAX,ICMAX
C IF MODE=0, THEN TEST RESULTS ENTERED SEQUENTIALLY
C IF MODE=1, THEN TEST RESULTS ENTERED SIMULTANEOUSLY
        READ(8,2) MODE
2       FORMAT(I1)
        DO 234 IJK=1,100
        R1(IJK)=0.
234     R2(IJK)=0.
        ITAG=0
        CALL INDATA
        WRITE(9,77)
77      FORMAT('1',T43,'AUTOMATED BAYESIAN RELIABILITY ASSESSMENT',
       1' MODEL'/1X,T43,'---------- -------- --- ---------- ----------',
       2 '-----'//1X,T57,'EDITED INPUT DATA'/
       2 1X,T57,'-----------------'///)
        WRITE(9,7)
7       FORMAT(1X,T38,'REFERENCE',
       1 T50,'CONFIGURATION      COMPONENT      COST ($) OF'/
       1 1X,T40,'INDEX',10X,'CODE',11X,'NUMBER',8X,'TESTING'/
       2 1X,T38,'---------    -------------    ---------',5X,
       3 '-------'/)
        DO 11 I=1,IMAX
11      WRITE(9,3)I,IC(I),ICN(I),ICOST(I)
3       FORMAT(1X,T41,I3,T53,I6,T71,I2,T86,I3)
        IC(1)=100000
        CALL PRIORS
        CALL SYSPRI(ITAG)
        IF(ITAG.EQ.1)GO TO 200
        CALL SYSREL
        WRITE(9,1101)
        WRITE(9,101)
1101    FORMAT(/////'1',T38,'ESTIMATES OF RELIABILITY DERIVED FROM ',
       1 'PRIOR DISTRIBUTIONS'/)
101     FORMAT( /1X,T33,'REFERENCE      BEST ESTIMATE',
       2 5X,'VARIANCE        (PSEUDO)       (PSEUDO)'/1X,T35,'INDEX',T52,
       3 'OF R',11X,'OF R',7X,'SUCCESSES      FAILURES'/1X,T33,3('-  '),5X,
       4 '---------  -------------            --------  ---------'/)
        DO 40 I=1,IMAX
        LSET=0
        VAR=R2(I)-R1(I)*R1(I)
        IF(VAR.LT.0)LSET=1
        IF(LSET.EQ.1)GO TO 200
        CALL BETA(R1(I),R2(I),A,B)
40      WRITE(9,1)I,R1(I),VAR,A,B
1       FORMAT(1X,T36,I3,T51,F7.4,T66,F7.4,T79,F8.2,T92,F7.2)
        IF(MODE.EQ.1)GO TO 60
50      CALL DECIDE
        GO TO 100
60      CALL TESTR
100     WRITE(9,102)
102     FORMAT(/////'1',T38,'ESTIMATES OF RELIABILITY DERIVED FROM ',
       1 'POSTERIOR DISTRIBUTIONS'/)
        WRITE(9,101)
        DO 150 I=1,IMAX
        VAR=R2(I)-R1(I)*R1(I)
        CALL BETA(R1(I),R2(I),A,B)
150     WRITE(9,1)I,R1(I),VAR,A,B
        GO TO 300
200     WRITE(9,301)
301     FORMAT(//' COMPONENT AND SYSTEM PRIORS ARE INCONSISTENT')
300     STOP
        END
C
C-----------------------------------------------------------------
C
        SUBROUTINE PRIORS
C
C IF HAVE SAME COMPONENTS IN DIFFERENT PARTS OF THE SYSTEM,
C     SHOULD SPECIFY PRIORS FOR CONSISTENCY
C
        DOUBLE PRECISION R1,R2,X1,X2,A,B
        COMMON R1(100),R2(100),IC(100),ICN(100),ICOST(100),
       1IMAX,ICMAX
        R1(1)=1./2
        R2(1)=1./3
        READ(8,1)NUMPRI
1       FORMAT(I2)
```

VI. LISTING OF PROGRAM CODE OF ABRAM (Continued)

```
      IF(NUMPRI.EQ.0)GO TO 10
C SAME COMPONENT MUST HAVE SAME PRIOR
C SYSTEM OR SUBSYSTEM TEST RESULTS ARE COMBINED WITH COMPONENT
C     TEST RESULTS BY INPUTTING THE FORMER AS SYSTEM OR
C     SUBSYSTEM PRIORS
      WRITE(9,36)
      WRITE(9,101)
      DO 10 I=1,NUMPRI
      READ(8,2)ICI,IA,IB
2     FORMAT(I5,2I3)
      IF(ICI.EQ.0)ICI=100000
      DO 20 J=1,IMAX
      IF(ICI.EQ.IC(J))GO TO 25
20    CONTINUE
25    A=IA
      B=IB
      CALL MOMNT(A,B,X1,X2)
      Y=X2-X1*X1
      IF(Y.LE.0.)GO TO 360
      WRITE(9,35)J,X1,Y,A,B
      R1(J)=X1
      R2(J)=X2
10    CONTINUE
101   FORMAT( /1X,T33,'REFERENCE     BEST ESTIMATE',
     2 5X,'VARIANCE       (PSEUDO)      (PSEUDO)'/1X,T35,'INDEX',T52,
     3 'OF R',11X,'OF R',7X,'SUCCESSES      FAILURES'/1X,T33,3('---'),5X,
     4 '------------            ---------     --------'/)
36    FORMAT(/////'1',T46,'SPECIFICATION OF PRIOR DISTRIBUTIONS ',
     1 'AND/OR'//1X,T52,'SYSTEM/SUBSYSTEM TEST RESULTS'/)
35    FORMAT(1X,T36,I3,T51,F7.4,T66,F7.4,T70,F8.2,T92,F7.2)
360   RETURN
      END
C
C----------------- ----------------------------
C
      SUBROUTINE INDATA
C
      DOUBLE PRECISION R1,R2
      COMMON R1(100),R2(100),IC(100),ICN(100),ICOST(100),
     1 IMAX,ICMAX
      READ(8,1) MAX,ICMAX
      DO 10 I=1,MAX
      READ(8,2) IC(I),ICN(I),ICOST(I)
10    CONTINUE
      IMAX=MAX
      DO 100 I=1,100
      IF(I.GT.IMAX)GO TO 150
      DO 75 J=1,5
      N=10**J
      M=10**(J-1)
      IDIGIT=MOD(IC(I),N)/M
      IF(IDIGIT.GT.1)GO TO 100
      IF(IDIGIT.NE.1)GO TO 75
      NCHEK=(IC(I)/N)*N
      DO 50 K=1,IMAX
      IF(IC(K).EQ.NCHEK)GO TO 100
50    CONTINUE
      IMAX=IMAX+1
      IC(IMAX)=NCHEK
      ICN(IMAX)=0
      ICOST(IMAX)=0
      GO TO 100
75    CONTINUE
100   CONTINUE
150   CONTINUE
      DO 250 I=1,IMAX
      DO 200 J=I,IMAX
      IF(IC(I).LE.IC(J))GO TO 200
      ICH=IC(I)
      IC(I)=IC(J)
      IC(J)=ICH
      ICNH=ICN(I)
      ICN(I)=ICN(J)
      ICN(J)=ICNH
      ICOSTH=ICOST(I)
      ICOST(I)=ICOST(J)
      ICOST(J)=ICOSTH
200   CONTINUE
250   CONTINUE
```

VI. LISTING OF PROGRAM CODE OF ABRAM (Continued)

```
1     FORMAT(2I3)
2     FORMAT(I5,I2,I3)
      RETURN
      END
C
C---------------------------------------------------------
C
      SUBROUTINE SYSPR1(ITAG)
C
      DOUBLE PRECISION R1,R2,ROLD,R1OLD,Z1,Z2,Z3,Z4
      COMMON R1(100),R2(100),IC(100),ICN(100),ICOST(100),
     1 IMAX,ICMAX
      DIMENSION L1(10),L2(10),L3(10),L4(10),L5(10)
C
C COUNTS NUMBER OF SERIAL SUBSYSTEMS, RECORDS INDEX FOR FUTURE USE
C     NX= THE NUMBER OF SYSTEM IN THE XTH LEVEL
C     LX= THE LOCATION OF THE XTH DIGIT SYSTEM
C     IX= THE XTH SYSTEM  BEING CONSIDERED
C
      ITAG=0
      N10=0
      N1=0
      IL=2
      IU=IMAX
      DO 10 I=IL,IU
      IF(MOD(IC(I),10000).NE.0)GO TO 10
      N1=N1+1
      L1(N1)=I
C TAKES OUT UNCERTAINTY, AND COUNTS NUMBER IF OVERRIDES
      IF(R1(I).EQ.0)GO TO 10
      R1(1)=R1(1)/R1(I)
      R2(1)=R2(1)/R2(I)
      IF(R1(1).GT.1)GO TO 105
      IF(R2(1).GT.1)GO TO 105
       N10=N10+1
10    CONTINUE
      N100=N1-N10
C SET UPPER LIMIT ON INDEX
      L1(N1+1)=IMAX+1
C
      IF(N1.EQ.0)GO TO 101
      DO 100 I1=1,N1
      II1=L1(I1)
      IF(R1(II1).NE.0)GO TO 15
C ALLOCATES REMAINING UNCERTAINTY
      R1(II1)=R1(1)**(1./N100)
      R2(II1)=R2(1)**(1./N100)
C
15    N20=0
      N2=0
      JL=L1(I1)+1
      JU=L1(I1+1)-1
      IJCHEK=I1
      IF(JU.LT.JL)GO TO 100
C COUNTER
      DO 20 J=JL,JU
      IF(IC(J)/10000.NE.IJCHEK) GO TO 20
      IF(MOD(IC(J),1000).NE.0)GO TO 20
      N2=N2+1
      L2(N2)=J
      IF(R1(J).EQ.0)GO TO 20
      ROLD=R1(II1)
      R1(II1)=1.-(1.-ROLD)/(1.-R1(J))
      R2(II1)=(1.-2*ROLD+R2(II1))/(1.-2*R1(J)+R2(J))+2*R1(II1)-1.
      IF(R1(II1).GT.1.)GO TO 105
      IF(R2(II1).GT.1.)GO TO 105
      N20=N20+1
C COUNTS NUMBER OF OVERRIDING
20    CONTINUE
      N200=N2-N20
      L2(N2+1)=JU+1
C
      IF(N2.EQ.0)GO TO 100
      DO 200 I2=1,N2
      II2=L2(I2)
      IF(R1(II2).NE.0)GO TO 25
C DON'T BOTHER WITH ITEMS THAT ALREADY HAVE A RELIABILITY
      Z1=(1.-R1(II1))**(1./N200)
      Z2=(1.-2*R1(II1)+R2(II1))**(1./N200)
      R1(II2)=1.-Z1
      R2(II2)=Z2+2*R1(II2)-1.
```

VI. LISTING OF PROGRAM CODE OF ABRAM (Continued)

```
C
25      N30=0
        N3=0
        KL=L2(I2)+1
        KU=L2(I2+1)-1
        INCHEK=I1*10+I2
        IF(KL.GT.KU)GO TO 200
        DO 30 K=KL,KU
        IF(IC(K)/1000.NE.INCHEK)GO TO 30
        IF(MOD(IC(K),100).NE.0)GO TO 30
        N3=N3+1
        L3(N3)=K
        IF(R1(K).EQ.0)GO TO 30
        R1(II2)=R1(II2)/R1(K)
        R2(II2)=R2(II2)/R2(K)
        IF(R1(II2).GT.1.)GO TO 105
        IF(R2(II2).GT.1.)GO TO 105
        N30=N30+1
30      CONTINUE
        N300=N3-N30
        L3(N3+1)=KU+1
C
        IF(N3.EQ.0)GO TO 200
        DO 300 I3=1,N3
        II3=L3(I3)
        IF(R1(II3).NE.0)GO TO 35
        R1(II3)=R1(II2)**(1./N300)
        R2(II3)=R2(II2)**(1./N300)
C
35      N40=0
        N4=0
        LL=L3(I3)+1
        LU=L3(I3+1)-1
        ILCHEK=I1*100+I2*10+I3
        IF(LL.GT.LU)GO TO 300
        DO 40 L=LL,LU
        IF(IC(L)/100.NE.ILCHEK)GO TO 40
        IF(MOD(IC(L),10).NE.0)GO TO 40
        N4=N4+1
        L4(N4)=L
        IF(R1(L).EQ.0)GO TO 40
        N40=N40+1
        R1OLD=R1(II3)
        R1(II3)=1.-(1.-R1OLD)/(1.-R1(L))
        R2(II3)=(1.-2*R1OLD+R2(II3))/(1.-2*R1(L)+R2(L))
       1+2*R1(II3)-1.
        IF(R1(II3).GT.1.)GO TO 105
        IF(R2(II3).GT.1.)GO TO 105
40      CONTINUE
        N400=N4-N40
        L4(N4+1)=LU+1
C
        IF(N4.EQ.0)GO TO 300
        DO 400 I4=1,N4
        II4=L4(I4)
        IF(R1(II4).NE.0)GO TO 45
        Z3=(1.-R1(II3))**(1./N400)
        Z4=(1.-2*R1(II3)+R2(II3))**(1./N400)
        R1(II4)=1.-Z3
        R2(II4)=Z4+2.*R1(II4)-1.
C
45      N50=0
        N5=0
        ML=L4(I4)+1
        MU=L4(I4+1)-1
        IMCHEK=I1*1000+I2*100+I3*10+I4
        IF(ML.GT.MU)GO TO 400
        DO 50 M=ML,MU
        IF(IC(M)/10.NE.IMCHEK)GO TO 50
        IF(MOD(IC(M),10).EQ.0)GO TO 50
        N5=N5+1
        L5(N5)=M
        IF(R1(M).EQ.0)GO TO 50
        N50=N50+1
        R1(II4)=R1(II4)/R1(M)
        R2(II4)=R2(II4)/R2(M)
        IF(R1(II4).GT.1.)GO TO 105
        IF(R2(II4).GT.1.)GO TO 105
50      CONTINUE
```

VI. LISTING OF PROGRAM CODE OF ABRAM (Continued)

```
              N500=N5 N50
              L5(N5+1)=MU+1
              IF(N5.EQ.0)GO TO 400
              DO 500 I5=1,N5
              II5=L5(I5)
              IF(R1(II5).NE.0)GO TO 500
              R1(II5)=R1(II4)**(1./N500)
              R2(II5)=R2(II4)**(1./N500)
        500   CONTINUE
        400   CONTINUE
        300   CONTINUE
        200   CONTINUE
        100   CONTINUE
              GO TO 101
        105   ITAG=1
        101   RETURN
        1000   FORMAT(I10,2X,F10.5,2X,F10.5)
              END
        C
        C---- -  -- ------ --- - ---- --- --  - ----------
        C
              SUBROUTINE SYSREL
        C
              DOUBLE PRECISION R1,R2,DMULT1,DMULT2
              COMMON R1(100),R2(100),IC(100),ICN(100),ICOST(100),
             1IMAX,ICMAX
              DIMENSION L(100)
              DO 1234 LL=1,100
        1234  L(LL)=0
              DO 100 ICOUNT=1,5
              N=10**(ICOUNT-1)
              ITAG=1
              IF(ICOUNT.EQ.2.OR.ICOUNT.EQ.4)ITAG=0
              DO 100 J=1,IMAX
              IF(L(J).EQ.1)GO TO 100
              IA=MOD(IC(J),10*N)/N
              IB=MOD(IA,10)
              IF(IA.EQ.0)GO TO 100
              IF(IB.NE.0)GO TO 50
              JS=J
              DMULT1=1.0
              DMULT2=1.
              GO TO 100
        50    IF(ITAG.EQ.1)GO TO 75
              DMULT1=DMULT1*(1-R1(J))
              DMULT2=DMULT2*(1 2*R1(J)+R2(J))
              R1(JS)=1-DMULT1
              R2(JS)=DMULT2+2.*R1(JS)-1.
              L(J)=1
              GO TO 100
        75    DMULT1=DMULT1*R1(J)
              DMULT2=DMULT2*R2(J)
              R1(JS)=DMULT1
              R2(JS)=DMULT2
              L(J)=1
        100   CONTINUE
              RETURN
              END
        C
        C--------------------------------------------
        C
              SUBROUTINE DECIDE
        C
              DOUBLE PRECISION R1,R2,R1H,R2H,X1,X2,A,B,APLUS1,
             1 R11,R12,BPLUS1,X3,X4,R21,R22
              COMMON R1(100),R2(100),IC(100),ICN(100),ICOST(100),
             1IMAX,ICMAX
              DIMENSION R1H(20),R2H(20)
        50    CRISK=(R2(1)-R1(1)**2)*100000
              WRITE(9,222)CRISK
        222   FORMAT(//'1',29H          THE CURRENT RISK IS,2X,F10.0)
              WRITE(9,11)
        11    FORMAT(/41X,T17,'COMPONENT      SYSTEM RISK      SYSTEM RISK',
             1 '      EXPECTED SYSTEM       CHANGE FROM      COST ($) PER UNIT'/1X,
             2T19,'NUMBER          IF SUCCESS         IF FAILURE        RISK IF TESTED',
             3'      CURRENT RISK        CHANGE IN RISK'/1X,T17,' - -------',
             4 5X,'  -    -    -   -  -  -        --  ----------        ',
             5' ---- --- -       --          - --    --')
```

VI. LISTING OF PROGRAM CODE OF ABRAM (Continued)

```
              DO 100 I=1,ICMAX
              K=0
              DO 30 J=1,IMAX
               IF(ICN(J).NE.I)GO TO  30
        C COUNTS NUMBER OF IDENTICAL COMPONENTS AND STORES VALUES
              K=K+1
              R1H(K)=R1(J)
              R2H(K)=R2(J)
        30    CONTINUE
        C
              CALL BETA(R1H(1),R2H(1),A,B)
              APLUS1=A+1
              CALL MOMNT(APLUS1,B,X1,X2)
              DO 40 J=2,IMAX
              IF(ICN(J).NE.I)GO TO 40
              R1(J)=X1
              R2(J)=X2
        40    CONTINUE
        C
              CALL SYSREL
              R11=R1(1)
              R12=R2(1)
              BPLUS1=B+1
              CALL MOMNT(A,BPLUS1,X3,X4)
              DO 60 J=1,IMAX
              IF(ICN(J).NE.I)GO TO 60
              R1(J)=X3
              R2(J)=X4
        C JH=LAST INDEX
              JH=J
        60    CONTINUE
        C
              CALL SYSREL
              R21=R1(1)
              R22=R2(1)
              RISK1=(R12-R11**2)*100000
              RISK2=(R22-R21**2)*100000
              ERISK=R1H(1)*RISK1+(1-R1H(1))*RISK2
              DRISK=CRISK-ERISK
              ECOST=ICOST(JH)/DRISK
              K=0
              DO 80 J=1,IMAX
              IF(ICN(J).NE.I)GO TO 80
              K=K+1
              R1(J)=R1H(K)
              R2(J)=R2H(K)
        80    CONTINUE
              WRITE(9,1)I,RISK1,RISK2,ERISK,DRISK,ECOST
        1     FORMAT(1X,T20,I3,T33,F8.2,T49,F8.2,T67,F8.2,T85,F8.2,T105,F8.2)
        100   CONTINUE
              READ(8,2)ICOMN,IA,IB
              XS=IA
              XF=IB
              IF(ICOMN.EQ.0)GO TO 120
        C ECHO PRINT COMPONENT SUCCESS AND FAILURES
              WRITE(9,5)ICOMN,XS,XF
        5     FORMAT(/'1',10X,'COMPONENT=',I3,3X,'SUCCESSES=',F3.0,3X,
             1  'FAILURES=',F3.0//)
              CALL UPDATE  (ICOMN,XS,XF)
              CALL SYSREL
              GO TO 50
        2     FORMAT(I2,2I3)
        120   CALL SYSREL
              RETURN
              END
        C
        C-------------- ---------   --   --- ---------- -
        C
              SUBROUTINE UPDATE(ICOMN,XS,XF)
        C
              DOUBLE PRECISION R1,R2,A,B
              COMMON R1(100),R2(100),IC(100),ICN(100),ICOST(100),
             1IMAX,ICMAX
              DO 100 I=1,IMAX
              IF(ICN(I).NE.ICOMN)GO TO 100
              CALL BETA(R1(I),R2(I),A,B)
              A=A+XS
              B=B+XF
              CALL MOMNT(A,B,R1(I),R2(I))
        100   CONTINUE
              RETURN
              END
```

VI. LISTING OF PROGRAM CODE OF ABRAM (Continued)

```
C
C ---------------------------------------------------
C
      SUBROUTINE TESTR
C
      DOUBLE PRECISION R1,R2
      COMMON R1(100),R2(100),IC(100),ICN(100),ICOST(100),
     1IMAX,ICMAX
      READ(8,1)NUMCOM
1     FORMAT(I2)
      WRITE(9,51)
51    FORMAT(//////'1',T55,'COMPONENT TEST RESULTS',///
     1 1X,T48,  'COMPONENT      SUCCESSES      FAILURES'/
     2  1X,T48, '---------      ---------      --------'//)
      DO 10 I=1,NUMCOM
      READ(8,2)ICOMN,IA,IB
      XS=IA
      XF=IB
      WRITE(9,50)ICOMN,XS,XF
50    FORMAT(1X,T51,I3,T65,F3.0,T79,F3.0)
2     FORMAT(I2,2I3)
      CALL UPDATE(ICOMN,XS,XF)
10    CONTINUE
      CALL SYSREL
      RETURN
      END
C
C---------------------------------------------------
C
      SUBROUTINE BETA(R1,R2,A,B)
      DOUBLE PRECISION R1,R2,A,B
C
      A=(R1*R1-R1*R2)/(R2-R1*R1)-1
      B=(1.-R1)*(A+1.)/R1-1.
      RETURN
      END
C
C---------------------------------------------------
C
      SUBROUTINE MOMNT(A,B,R1,R2)
      DOUBLE PRECISION R1,R2,A,B
C
      R1=(A+1)/(A+B+2.)
      R2=R1*(A+2.)/(A+B+3.)
      RETURN
      END
```

PART 4

SURVEY AND TESTING ORGANIZATIONS IN DOD

PART 4

SURVEY AND TESTING ORGANIZATIONS IN DOD

In this part of the report, we present a directory of Service organizations involved in reliability testing, and the results of our survey of these organizations.

I. DIRECTORY OF ORGANIZATIONS SURVEYED

The purpose of this section is to present an overview of organizations in each of the Services involved in reliability assessment. Generally, there are five major activities in reliability assessment in which these organizations are involved.

- Research of new methods of assessing reliability and establishing requirements for new systems;
- Development of new systems or items of equipment from initial design through contract award, prototype development, and pre-production testing;
- Field Testing systems at various development phases, prior to final production, and at intervals during in-service lifetime;
- Logistical Support of systems, providing a supply of spares, maintenance, and assuring the operational readiness of systems; and
- Reliability, Maintainability, and Quality Assurance policy guidance development.

A Program Manager is usually assigned the primary responsibility for development of a particular system. Depending on factors such as the cost and importance of the system, an individual or group of individuals is assigned responsibility for reliability growth and assessment.

Expertise in all the above-mentioned areas is expected to be used by the Program Manager during the development phase. A description of the manner in which the responsibilities for reliability assessment are carried out in each of the Services follows.

A. U. S. ARMY

Reliability assessment activities are carried out under the purview of three of the five Deputy Chiefs of the Army, as shown schematically in Exhibit 1 on the following page.

- Deputy Chief of Staff for Research Development and Acquisition (DCSRDA) - generally responsible for developing future improvements and advising on scientific and evaluation issues. The Operational Test and Evaluation Agency (OTEA) reports to DCSRDA as do other field and staff support agencies involved in this type of activity.

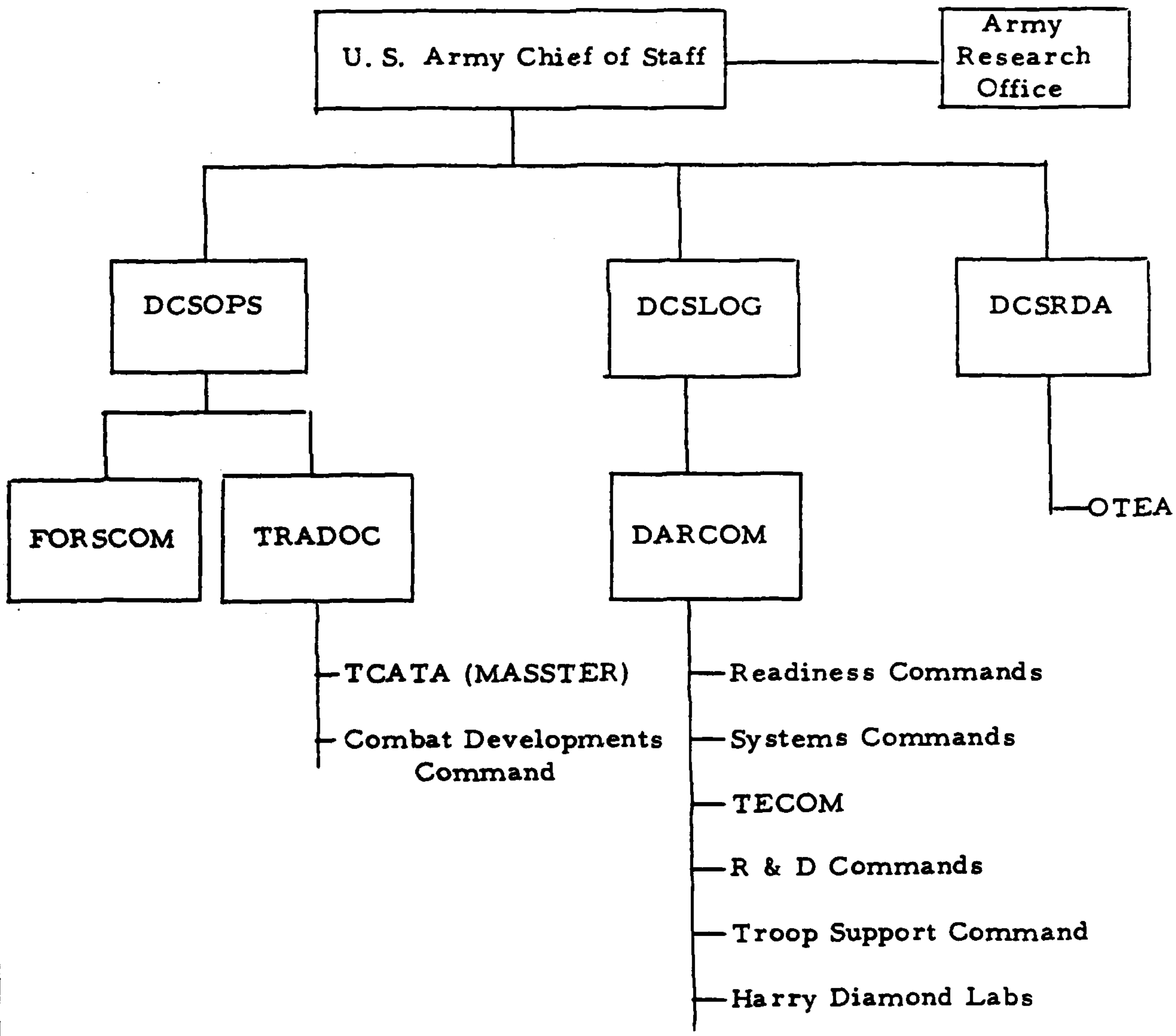
- Deputy Chief of Staff for Logistics (DCSLOG) - responsible for operational availability, control of inventories, and the management of weapon system and equipment development. The Material Development and Readiness Command (DARCOM) is under the staff purview of DCSLOG.

- Deputy Chief of Staff for Operations and Plans (DCSOPS) - has purview over two commands: Forces Command (FORSCOM) and Training and Doctrine Command (TRADOC). The former is responsible for field strength and operations. The latter command supervises CONUS Army schools involved in training activities and doctrine development, MASSTER, the major field test operation at Fort Hood, Texas, and the Combats Development Command (CDC).

Reliability contracts within these agencies and commands are given below along with brief descriptions of their interaction in the reliability growth and assessment processes.

Exhibit 1

U. S. ARMY ORGANIZATIONS INVOLVED IN RELIABILITY TESTING AND ASSESSMENT



1. Development & Acquisition

The development and acquisition of major systems is coordinated by twenty-two project managers within DARCOM's Office of Project Management. Procurement and development of components and subsystems are carried out by product managers within the various agencies and commands. Certain high-cost systems, however, such as the XM1 tank and the Advanced Helicopter are handled by program managers at the DOD level. These DARCOM project managers are autonomous in that they report directly to the Secretary of the Army when required. Project Managers prescribe their own reliability assessment plans under the command's general policies.

DARCOM is responsible for logistical support as well as acquisition and development. The various commands within DARCOM are split into readiness (logistics) and development oriented commands. Reliability, availability, and maintainability (RAM) functions are considered part of product assurance and are overseen by the Reliability and System Assessment Division of the Directorate for Quality Assurance (Mr. A. Nordstrom 202/274-8912) at DARCOM Headquarters. Each of the ten commands in DARCOM has RAM personnel involved in product assurance for new material development and in the analysis of data generated during operational and storage phases of item life cycles. A list of RAM contacts for the ten commands is given below.

- ARRCOM: Armament Materiel Readiness Command, Rock Island, Illinois. Mr. Robert McKeague 309/794-4851.
- ARRADCOM: Armament Research and Development Command, Dover, New Jersey. Mr. Dale Adams 201/794-6671.
- AVRADCOM: Aviation Research and Development Command, St. Louis, Missouri. Mr. Robert Neff 314/268-2541.
- MIRCOM: Missile Materiel Readiness Command, Redstone Arsenal. Mr. Carl Coxsey 205/876-5281.
- MIRADCOM: Missile Research and Development Command, Redstone Arsenal. Mr. William Walker 205/876-7570.
- MERADCOM: Mobility Equipment Research and Development Command. Fort Belvoir, Virginia. Mr. Lynwood Rabon 703/664-6402.
- TARCOM: Tank-Automotive Materiel Readiness Command, Warren, Michigan. Mr. Edward Polomski 313/264-1100.
- TARADCOM: Tank-Automotive Research and Development Command, Warren, Michigan. Mr. Wilbert Simkowitz 313/573-2860.
- TSARCOM: Troop Support and Aviation Materiel Readiness Command, St. Louis, Missouri. Mr. Vail Miller 314/263-2464.

Other commands under DARCOM are:

- CORADCOM: Communications R&D Command
- ERADCOM: Electronics R&D Command
- CERCOM: Communications & Electronics Command
- TECOM: Test and Evaluation Command

In addition, DARCOM manages several labs:

- Natick R&D Command: involved in testing of equipment resistance to environmental extremes;
- Harry Diamond Labs: involved in testing to conduct stress and corrosion analysis and the impact of various noxious environments on various materials and other basic research activities.

2. Testing and Evaluation

The U.S. Army places heavy emphasis on removing operational problems prior to introduction of systems into field use. As shown in Exhibit 3, DCSOPS has two sides: FORSCOM, which is not involved with reliability assessment or testing, and TRADOC, the training and doctrine development side, which is responsible for ensuring that the new equipment or weapons can be efficiently used by the troops. To accomplish its mission, TRADOC controls three primary activities: training, doctrine and tactical development, and field activities. Doctrine and tactical development has long been the purview of the Combat Developments Command (CDC), which is now part of TRADOC. CDC interacts with the schools and various forces and is generally responsible for generating Qualitative Material Requirements (QMR's) to satisfy future needs. TRADOC's field test activities are centered in project MASSTER (the Modern Army Selected System Test, Evaluation, and Review) at Fort Hood, Texas. MASSTER, newly designated as TRADOC Combat Arms Test Activity (TCATA), brings together groups involved through the design and development cycle, regardless of

their organizational affiliation, in its comprehensive field trials and operational tests. It is at this point that TRADOC's System Managers assume responsibility for the system from the Project Managers and begin to integrate it into supply depots and field use. DARCOM is, of course, still responsible for the logistical support.

The White Sands test facility, used primarily by MICOM, is operated by Fort Bliss personnel. It is jointly administered by DARCOM and TRADOC. Ballistic testing is conducted at Aberdeen Proving Grounds (APG) under DARCCM supervision. However, TECOM conducts most of the APG testing activity to validate or try-out new QMR concepts.

Each of the services has an independent test agency. The Army's is the Operational Test and Evaluation Agency (OTEA) located in Falls Church, Virginia. OTEA reports to DCSRDA and is responsible for certification of the produced system for field use. OTEA tests major systems and sub-systems in operational environments attempting to integrate tactics, troops, doctrine support, etc., in realistic settings. These tests do not focus as much on reliability as on operational questions, such as whether the troops operate the hardware. OTEA conducts tests at bases throughout the world. However, TCATA facilities at Fort Hood are used so frequently that they maintain an office at that base. The contact is: Mr. Virgil Henson, Chief Analyst, TCATA, Fort Hood, Texas 817/532-9203. The OTEA contact for RAM assessment is Mr. Frederick McCoy, 202/756-1028.

Test plans are usually developed by a team, its members representing the development and production aspects, operational needs, logistics, human factors, and statistics.

3. Individuals Contacted

The following persons were contacted during the survey phase:

- Mr. Arthur Nordstrom, Chief, Reliability and System Assessment Division, DARCOM, 202/274-8912.
- Mr. Larry Crow, Armament Materiel Systems Analysis Activity (AMSAA), Aberdeen Proving Grounds, 301/278-3280.
- Mr. Louis Iannuzzelli, Armament Materiel Readiness Command, 309/794-4851.
- Mr. John Obren, Director, Product Assurance Directorate, Armament Materiel Readiness Command, 309/794-4851.
- Mr. Robert Launer, Army Research Office, 919/549-0641.
- Dr. Jag Chandra, Director, Army Research Office, 919/549-0641.

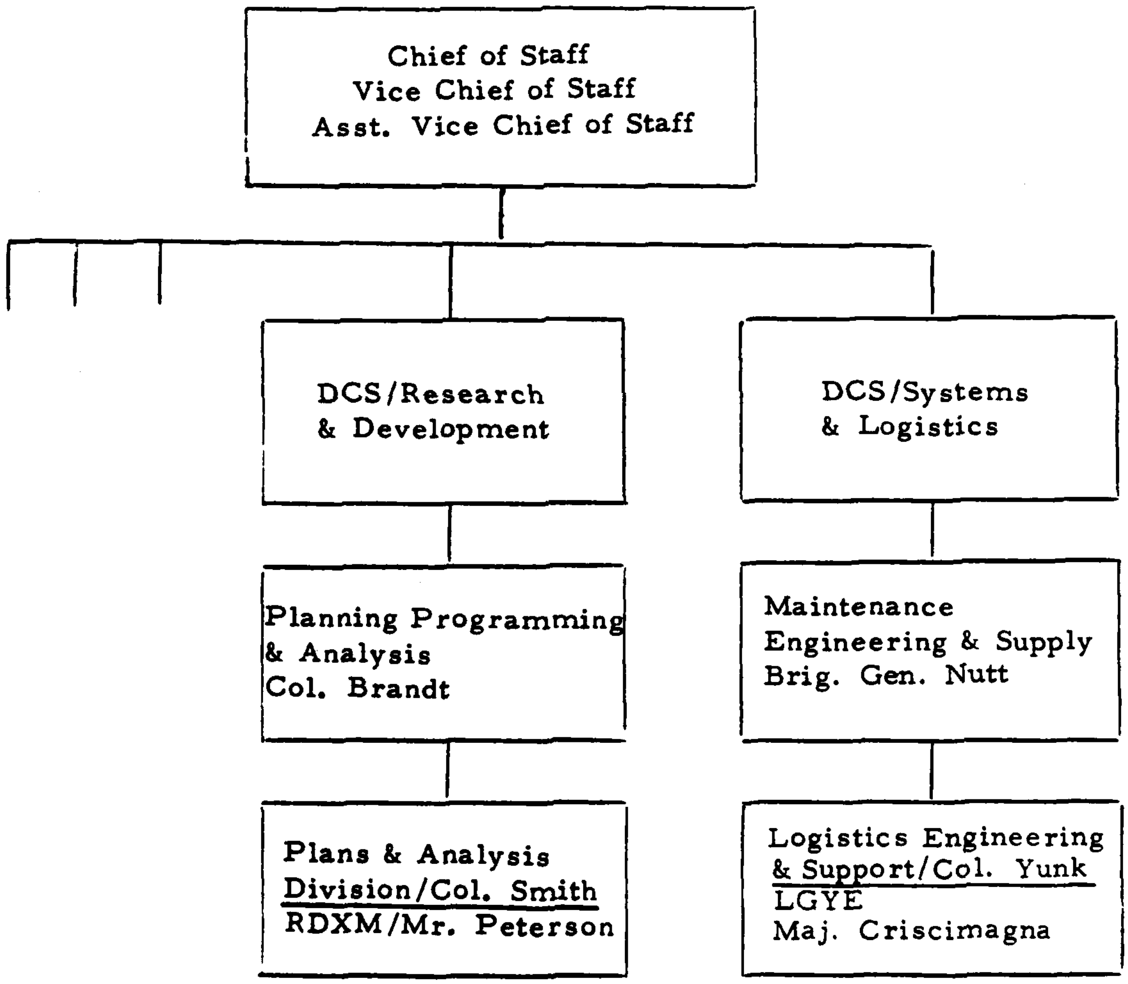
B. U. S. AIR FORCE

Reliability, availability, and maintainability policy is established within two of the five Offices of the Deputy Chiefs of Staff of the Air Force as shown schematically in Exhibit 2 on the following page.

- DCS/Research and Development (DCSRD) - generally responsible for development and acquisition of new systems; for coordinating planning and program analysis and for developing operational requirements of new systems.
- DCS/Systems and Logistics (DCSSL) - generally responsible for procurement of production approved systems and for their logistic support.

Exhibit 2

ORGANIZATIONS RESPONSIBLE FOR COORDINATING RELIABILITY ASSESSMENT AT THE AIR FORCE HEADQUARTERS LEVEL



The Office of Primary Responsibility (OPR) for overall reliability policy for the Air Force is Logistics Engineering and Support Division (LGYE). Reliability testing and analysis policy is coordinated by the RDXM within the Directorate of Planning, Programming and Analysis under the DCS/RD in conjunction with the LGYE of the Directorate of Maintenance Engineering and Supply under DCS/SL.

In general, systems acquisition and development is directed by program managers within the implementing command which is normally the Air Force Systems Command (AFSC).

Acquisition and system development are coordinated by program managers within the Air Force Systems Command (AFSC). [Development and acquisition of most systems are accomplished by AFSC through an AFSC-assigned Program Manager (PM)] . The PM is ultimately responsible for all aspects of the system, including achievement of RAM objectives. The role of AFLC is that of coordinator/monitor. AFLC is responsible for advising on logistics supportability aspects and for planning for operational logistics support. However, the decision authority remains with the Program Manager (AFSC). Basic organizations within AFSC and AFLC are shown in Exhibits 3a and 3b. The Air Force's independent test agency is located at the Air Force Test and Evaluation Center (AFTEC) at Kirtland Air Force Base. Reliability assessment contracts within these

Exhibit 3a

ORGANIZATIONS OF AFSC

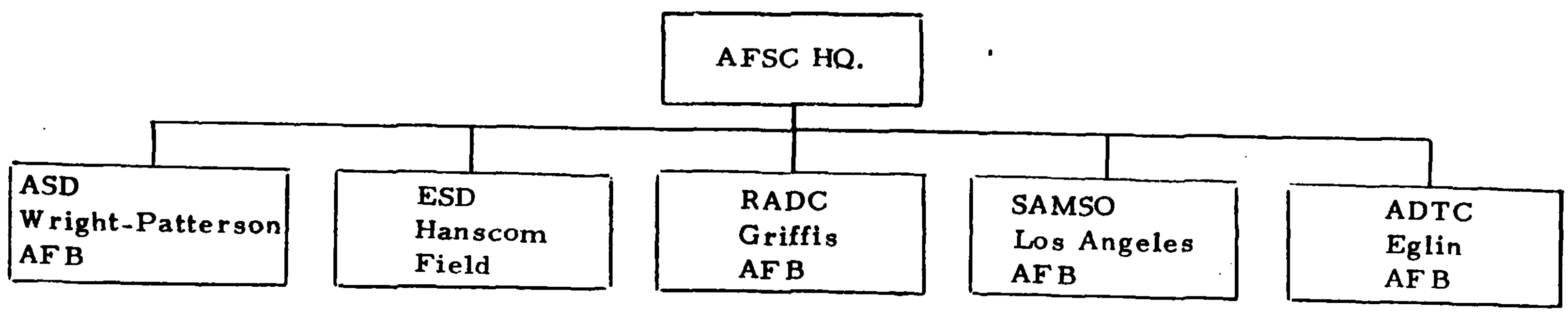
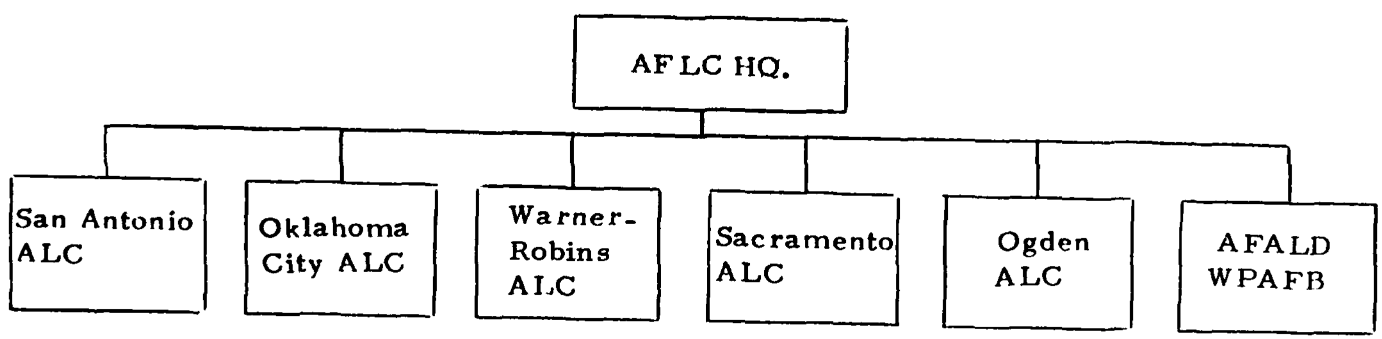


Exhibit 3b

ORGANIZATIONS OF AFLC



agencies and commands are given below along with brief descriptions of their interaction in the reliability growth and assessment processes.

1. Development & Acquisition in AFSC

Program Managers are located within four major product divisions of AFSC as shown in Exhibit 3a:

- Electronic Systems Division at Hanscom Field
- Aeronautical Systems Division at Wright-Patterson Air Force Base
- Space and Missile Systems Organization headquartered at Los Angeles Air Force Station
- Armament Development and Test Center at Eglin Air Force Base

The OPR for RAM for AFSC is Major Guy A. Morgan, SDDE, 301/981-3316.

In addition to the above divisions, AFSC also has several laboratories and Flight Test centers. The labs, with a few exceptions (such as RADC, and the Flight Dynamics Laboratory at WPAFB), do not have reliability assessment responsibilities. Although tests designed to cause item failures are conducted, they are usually for new experimental products under special conditions and, hence, usually do not generate data usable for reliability assessment.

During the development of a system, the contractor is responsible to design, test, and make his evaluation of the system, subsystems, and

its various components. In general, the contractor's test plans and procedures are approved by the Program Manager who arranges for USAF test facilities as necessary. Test and evaluation (T & E) Master Plans are prepared by the responsible test organization (usually AFSC) and program management office. The independent test and evaluation agency, AFTEC, conducts operational testing and evaluation (OT & E) on early production models. Operational test requirements, established by AFTEC and/or the operating command, include (1) assessment of operational capabilities, (2) development of tactics and procedures, and (3) evaluation of logistic support capability. AFTEC continues these tests on production units even after the first units are accepted by the users.

2. Testing & Evaluation in AFLC

The AFLC conducts continuing assessment of the reliability of operational systems through its five Air Logistic Centers and one Acquisition Logistics Division.

- San Antonio Air Logistics Center
- Oklahoma City Air Logistics Center
- Warner-Robins (Georgia) Air Logistics Center
- Sacramento Air Logistics Center
- Ogden, Utah Air Logistics Center
- Air Force Acquisition Logistics Division

The focal point of reliability for the five centers is AFLC/LO (Mr. Craig Gridley, 513/257-3435, WPAFB). The Acquisition Logistics Division of AFLC interfaces with acquisition agencies to ensure that a more supportable system is developed. This division contains a reliability group which often works with the program office to introduce the logistic point of view early in the development cycle. (The AFALD focal point for RAM is Mr. William Romas, PTEA, 513/255-4028, WPAFB.)

The producibility, reliability, availability, and maintainability (PRAM) program office at Wright-Patterson Air Force Base is responsible for tracking systems after initial production and operational costs. Each of the five Air Logistics Centers have a PRAM unit to which they assign their own personnel. PRAM uses data from in-service testing, but does not design reliability assessment tests.

3. Individuals Contacted

- Maj. Ned Criscimanga, HQ USAF, LGYE, Engineering and Support Division, 202/695-0080
- Mr. Elmer Peterson, HQUSAF RDXM, Office of Planning and Program Analysis, 202/697-6093
- Mr. I. N. Shimi, Directorate of Math and Information Sciences, Air Force Office of Scientific Research, 202/767-4939
- Capt. Herbert LaFlame, PRAM Element Manager, HQAF, RDPV, 202/697-5414
- Mr. Tony Athens, Air Force Logistics Command, San Antonio Air Logistics Center, 512/925-8961

- Col. John Hager, Scientific Advisory Board, 202/697-8845
- Mr. Anthony Coppola, RADC/RBRT, 315/330-4726
- Mr. Jerome Klion, RADC/RBRT, 315/330-4726
- Mr. Tony Pettinato, RADC, Engineering Support Electronics Division, 315/330-4726
- Mr. Marion Williams, Chief Technical Advisor, Analysis Directorate, AFTEC/OA, 505/264-3316
- Maj. Guy Morgan, Reliability and Maintainability Staff, AFSC, SDDE, 301/981-3316
- Col. Glen O'Banion, AFTEC, Director of Logistics, 505/264-0321
- Mr. David Barber, RADC, 315/330-4726
- Col. Ben Swett, ODDR & E(T&E), 202/697-1130
- Mr. Jan Howell, AFFTC/DOEES, 213/350-3066
- Capt. Mahlon H. Long, ADTC/SDEP, 305/872-3674
- Mr. Charles Burneka, ASD/ENES, 216/478-4913
- Mr. Frank Van Horn, ESD/DRT, 207/478-4913
- Lt. Col. Kenneth Blakney, SAMSO/AWSR, 213/833-1182

C. U. S. NAVY

All reliability test planning and assessment activities are conducted within the Naval Materiel Command in the Navy with the exception of those conducted by the independent test and evaluation agency, Comprehensive Operational Test and Evaluation Force (COMOPTEVFOR), which reports to the Director of Research, Development, Training and Evaluation. The organizational structure of the Navy is depicted in Exhibit 4. Within the

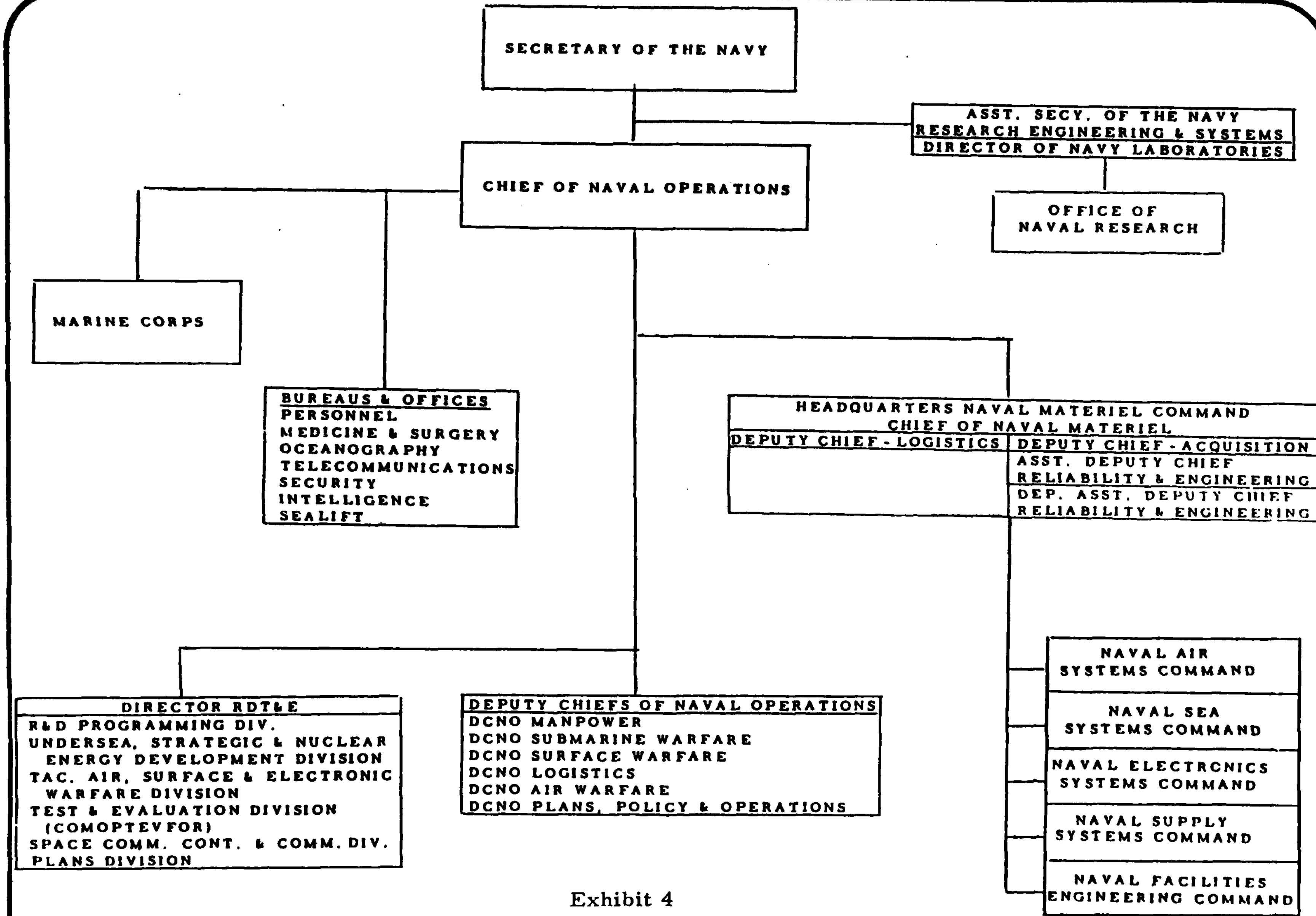


Exhibit 4

U.S. NAVY ORGANIZATIONS INVOLVED IN RELIABILITY ASSESSMENT

Materiel Command there are five systems commands. Three, namely NAVELEX, NAVAIR, and NAVSEA, have their own logistic support organizations, test facilities, development programs, and reliability expertise. Overall reliability policy for the Materiel Command is set by the Deputy Chief of Naval Materiel, Reliability and Engineering.

The development function in the three systems commands is generally carried out by a designated program or project manager who takes the project from the initial need determination through technical and operational evaluation. When these last evaluations are satisfied, production is given the go-ahead and the program manager's office is usually disbanded. Designated program managers report directly to the Commander of each systems command. Other development activities, which occur prior to designation of project office or are small scale efforts, may often be found within specific existing offices.

Testing and reliability assessment go on throughout the development cycle. The project manager either hires needed experts to work in his office or draws on the reliability assessment expertise that exists within his command, especially the expertise that is pertinent to the equipment being developed (sonar, power plants, etc.).

Reliability assessment activities peculiar to each of the three systems commands are discussed in detail below.

1. NAVAL SEA SYSTEMS COMMAND (NAVSEA)

NAVSEA contains the old Naval Ordnance Systems Command and the Naval Ship Systems Command. Its directorates which are directly or indirectly involved with reliability assessment are as follows:

- Nuclear Power Directorate (08)
- Weapons Systems and Engineering Directorate (06)
- Fleet Support Directorate (04)
- Research and Technology Directorate (03)
- Reliability, Maintainability, and Quality Assurance Directorate (RM&QA) (98)

The first two listed are responsible for program development activities. The third, the Fleet Support Directorate, is concerned with logistical support. The Research and Technology Directorate is responsible for the development of new systems prior to approval for full-scale development. Finally, the RM&QA Directorate oversees the reliability, maintainability, and quality assurance activities of the program office.

a. Development and Acquisition

Development and acquisition activities, other than for Nuclear Propulsion Systems and Ships, are focused within the Weapons Systems and Engineering Directorate (06). This directorate is responsible for field activities as well as life cycle development and management, fire controls, sonar, torpedoes, and other weapon related systems. Development activities can actually begin within the Research and Technology Directorate prior to

designation of a program or project managers (PM's) in 06. Also, there are project offices within the Fleet Support Directorate and some, such as the Polaris Office, which report directly to the Chief of Naval Materiel.

During development, PM's call on the existing expertise within the various directorates and offices of NAVSEA, and, in particular, within 06. The three reliability assessment contacts within 06 are:

- Mr. Anthony Frizalone, Surface Weapons Division, 202/692-1422.
- Mr. John Fleischman, Underwater Weapons Division, 202/692-7896.
- Mr. Toshio Oishi, NAVSEC, 202/692-6423.

These three offices help the PM's in establishing test plans for preproduction tests, environment qualification tests, and R&M demonstration tests and assessment. They also act as technical consultants for other aspects of reliability programs.

b. <u>Testing and Evaluation</u>

All NAVSEA testing is coordinated through the Test and Evaluation Office of the Weapons System and Engineering Directorate. This office, currently under the direction of Captain Horowitz (06N), provides overall NAVSEA coordination with COMOPTEVFOR. In addition, the RM&QA Directorate monitors all reliability assessment activities, reviews test plans for timeliness and cost effectiveness, participates in design reviews, and coordinates all approval recommendations. The Directorate also follows the system into operation to see if it attains its R&M goals in the fleet.

The Test and Evaluation Office also supports Weapons Quality Engineering Centers (WQEC's) at Yorktown, Concord, Seal Beach, Indian Head, Keyport, Corona, and Crane, Indiana. The WQEC's conduct reliability testing on assigned products, mostly expendable weapons munitions. They are under the direction of Captain Horowitz (06N) in the Test and Evaluation Office (202/692-8212) which provides overall NAVSEA coordination with COMOPTEVFOR.

The Test and Evaluation Office coordinates with the following:

- Fleet Analysis Center (FLEETAC), Corona, California - Analyzes RM&A data from the fleet. Mr. Howard Clark, 714/736-4211.
- Concord Test Center, Concord, California - Tests munitions (bullets). Mr. Lawrence Nichols, 415/671-2219.
- Seal Beach. Reliability tests on ASROC, SUBROC, Marine Corps Munitions and Missiles and all TAC and STRATEGIC Nuclear Weapons. Integrate lab data and do joint service and DOE Nuclear safety testing. Mr. Lawrence Grey, 213/596-9489.
- Naval Torpedo Station, Keyport Washington, Mr. Charles Thorn, 206/396-2271.
- Naval Weapons Station, Yorktown, Virginia - Tests of underwater mines and demolitions. Jeff Lamb, 804/887-4886.
- Indian Head, Indian Head, Maryland. Mr. John Henderson, 301/743-4324.

All ranges, such as Point Mugu and AWFTF, are managed by NAVAIR. The tests at the above facilities are mostly of expendables.

NAVSEA does not do much in-service testing. Instead, they use 3M data and extensive simulation modeling. Reliability assessment follows a similar pattern in NAVAIR and NAVELEX.

2. NAVAL AIR SYSTEMS COMMAND (NAVAIR)

a. Development & Acquisition

Acquisition and development are coordinated by 24 program managers (PMA's) within the Directorate for Plans and Programs (01). As in NAVSEA, although the program managers' offices are usually staffed to handle reliability planning, they often turn to other NAVAIR agencies for technical assistance in areas such as avionics, power plants, and reliability assessment.

Other directorates involved in or concerned with reliability are:

- Test and Evaluation (06)
- Air Logisitics (04)
- Weapons Systems (05)
- Research and Technology (03)

As noted above, program managers are within AIR 01 but some product managers are within AIR 05. Also within AIR 05 is a Relabiility and Maintainability Groups (AIR 5205), headed by Mr. James Wiggins, 202/692-7595. This group works with the PMA's by:

- analyzing failure data;
- establishing reliability criteria;
- reviewing designs;
- investigating failures; and
- assisting in developing reliability program plans.

NAVAIR has a special reliability and maintainability group in 03 which develops new R&M applications and methods and develops new methods of applying R&M to military systems. For example, in one project the group is exploring R&M procedures to use early in the development cycle. Contacts within this group are:

- Mr. Steven Hurst, Assistant Technical Administrator for Logistics, Hydraulics, Mechanical Equipment and Fluidics.
- Mr. Fred Hall, Administrator, Reliability and Maintainability for Advanced Technology Programs (3406).

Both can be reached at 202/692-7443. Mr. Hall is also NAVAIR's representative on the inter-services task force for improved R&M.

b. Testing and Evaluation

Testing is coordinated by the Test and Evaluation Directorate (AIR 06), whose functions include:

- manage and modernize T&E Bases including all munitions test facilities used by NAVSEA and NAVALEX as well as NAVAIR:
- assist NAVAIR Program Managers in structuring the best T&E plan, set in with Program Office staff, work with contractors, ensure T&E plan is timely and cost-effective and that it complies with policy, and with acquisition plans in DOD Directorates 5000. 1, .2 and .3.

Detailed test contents are worked out by the engineers in AIR 05.

Currently, emphasis is being placed on (1) using simulations to assess reliability in the Navy since test resources are scarce, systems more costly than ever, and RAM personnel bogged down in current problems; and (2) following up failures and fixes in the R&D cycle to know what to look for in operational and acceptance testing. Interest in the simula-

tion approach stems from the DOD level where a survey on simulation is currently being administered by Air Munitions Requirements and Development Command.

3. NAVAL ELECTRONICS COMMAND (NAVELEX)

a. Development and Acquisition

Development and acquisition of major systems are coordinated by seven Project Managers (PME's) who report directly to the Chief of NAVELEX. Acquisition of other items and products is coordinated by Acquisition Managers. The directorates involved in reliability assessment are:

- Logistics (04)
- Research and Technology (03)
- Material Acquisition (05).

Reliability test plans are developed by the PME's and acquisition managers with the OPR within 04: Mr. William Wallace (4702), Reliability Branch Head, 202/692-7526. This office has sign-off authority on all test plans and also performs a monitoring function with the PME's similar to Code 98 in NAVSEA. Test and evaluation coordination is handled by Capt. L. A. Dwyer (05E) whose office sets up the T&E Master Plans with the PME's and coordinates with COMOPTEVFOR for completion to OPEVAL. NAVELEX has one test facility at Saint Indigoes, Maryland--Naval Electronics Systems Test and Evaluation Detachment (NESTED).

4. INDIVIDUALS CONTACTED IN ALL COMMANDS

NAVSEA

- Mr. Howard Fleck (98), Deputy Commander for Reliability, Maintainability and Quality Assurance, 202/692-3387.
- Mr. Anthony Frizalone (06-G2), Division Director, Reliability and Quality Engineering (Surface Weapons), 203/692-1426.
- Mr. Henry Itkin (06-G2), Assistant for Reliability Statistical Analysis, 703/692-1426.
- Mr. John Fleischman (06-H5), Director, Assurance Engineering Office (Underwater Weapons), 202/692-7896.
- Mr. Steven Robling (06-N1), Director of Systems Evaluation Division, Test and Evaluation Trials and Readiness Office, 202/692-8212.
- Mr. Melvin Landis (9821), Reliability and Maintainability Engineer, 702/692-0415.
- Mr. Toshio Oishi (61-81B), Chief Effectiveness Section Naval Systems Effectiveness Command, 202/692-6423.
- Ms. Beatrice Orleans, Chief Statistician, 202/692-9514.
- Mr. Morton Buckberg (61-12), Reliability Section Head, Naval Ship Engineering, 202/692-2150.
- Mr. Donald Johnson (04-C), Technical Director, 202/692-3526.

NAVAIR

- Mr. James R. Wiggins (5205), Branch Head Reliability and Maintainability, 202/692-7595.
- Mr. Fay Norton (52051), Reliability Engineer, 202/692-7595.
- Mr. Fred Hall (340G), Administrator, Reliability and Maintainability, 202/692-7443.

NAVELEX

- Mr. William Wallace (4702), Reliability Branch Head, 202/692-7526.

OTHERS

- Capt. G. D. Webber (348CP5), Deputy Assistant, Reliability and Engineering, 202/692-1106.
- Mr. Bruce McDonald (436), Statistician, Office of Naval Research, 202/692-4315.
- Mr. Ken LaSalla, Assistant Director, Program Assessment Division, Reliability and Engineering, 202/692-1748.

D. MARINE CORPS

Most of the Marine Corps systems and equipment are procured in conjunction with Army or Navy procurements. In these cases, the Marine Corps will act in a review capacity to RAM assessment and other development issues. However, the Marines do their own testing and reliability assessment for amphibious vehicles.

As in the other services, development efforts are managed by an Acquisition Program Officer. Two managers, Mr. John J. Durant (202/694-2306), and Mr. Gilbert T. Lussier (202/694-2306), handle 33 development programs without special assistance in any of the technical areas, such as finance, quality assurance, training, or logistics. They are responsible for four primary functions:

- value engineering;
- quality assurance;
- configuration management; and
- reliability, availability, and maintainability.

The independent test activity is conducted at the Marine Corps Development and Education Center at Quantico by the Marine Corps Tactical Systems Support Activity (MCTSSA). The MCTSSA contact for amphibious vehicles is Mr. John Carr, 703/640-2242.

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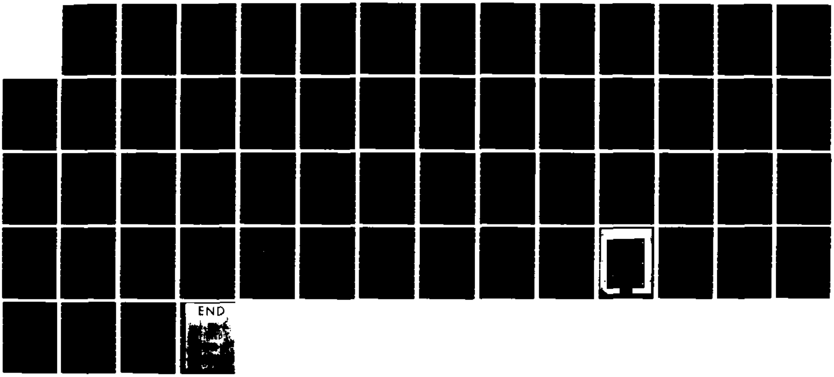

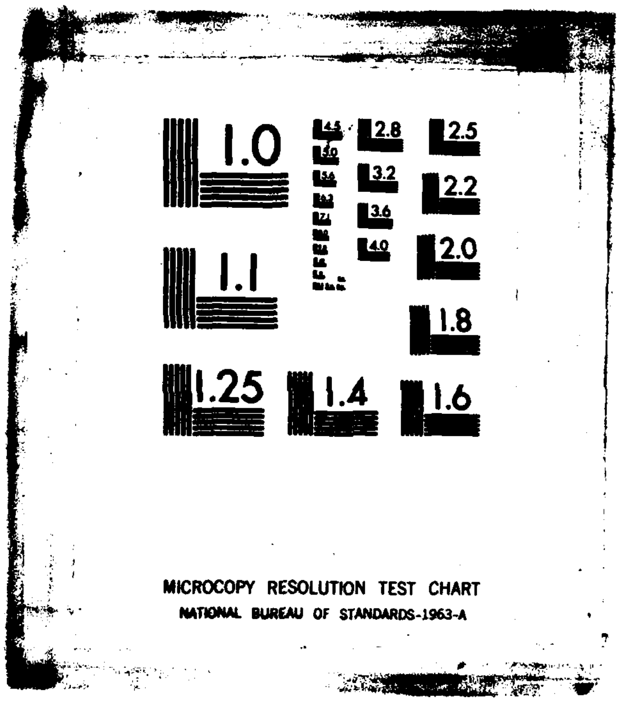
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E. TEST FACILITIES IN THE DEPARTMENT OF DEFENSE

The test facilities in DOD can be divided into two groups as follows:

1. NATIONAL RANGES

Those major DOD ranges and test facilities which are unique national assets designed to support requirements of major DOD programs and other Federal Government Agencies.

National Ranges	Management Agency
White Sands Missile Range (WSMR)	U.S. Army
Kwajalein Missile Range (KMR)	U.S. Army
Pacific Missile Range (PMR)	U.S. Navy
National Parachute Test Range (NPTR)	U.S. Navy
Eastern Test Range (ETR)	U.S. Air Force
Space & Missile Test Center (SAMTEC)	U.S. Air Force
Satellite Control Facility (SCF)	U.S. Air Force
Arnold Engineering Development Center (AEDC)	U.S. Air Force

2. DOD MAJOR TEST FACILITIES

Those other major DOD test facilities which support, almost entirely, DOD requirements:

Test Facilities	Management Agency
Dugway Proving Ground (DPG)	U.S. Army
Arctic Test Center (ATC)	U.S. Army
Tropic Test Center (TTC)	U.S. Army
Yuma Proving Ground (YPG)	U.S. Army
Jefferson Proving Ground (JPG)	U.S. Army
Electronic Proving Ground (EPG)	U.S. Army
Aberdeen Proving Ground (APG) (Materiel Test Directorate Only)	U.S. Army
Atlantic Underwater Test & Evaluation Center (AUTEC)	U.S. Navy
Naval Air Test Center (NATC)	U.S. Navy
Naval Air Propulsion Test Center (NAPTC)	U.S. Navy
Naval Air Test Facility (NATF)	U.S. Navy

Test Facilities	Management Agency
Naval Weapons Center (NWC) (T&E Portion Only)	U.S. Navy
Atlantic Fleet Weapons Range (AFWR)	U.S. Navy
Air Force Special Weapons Center (Incl. 6585th Test Group) (AFSWC)	U.S. Air Force
Tactical Fighter Weapons Center (TFWC) (Continental Operations Range Only)	U.S. Air Force
Air Force Flight Test Center (AFFTC)	U.S. Air Force
Armament Development and Test Center	U.S. Air Force
Air Defense Weapons Center (ADWC)	U.S. Air Force

II. PURPOSE AND SCOPE OF SURVEY

This section presents the results of a brief survey of the current reliability assessment programs in the Army, Air Force, Navy, and Marine Corps. The categories of information sought were:

- organizations involved in reliability assessment;
- resources expended on testing;
- potential for reducing test costs by using prior information on component reliability;
- obstacles or barriers to the utilization of Bayesian techniques;
- amenability to demonstration of "A Bayesian Scheme for Sequentially Testing a Multi-Component System."

Approximately 50 interviews were conducted by telephone or in person using an interview guide shown in Section V. Among the interviewees were persons in coordinating roles, research scientists, statisticians, and program development managers. The variation in roles, perspectives, and backgrounds of the interviewees made standardization of the questions--and, hence, statistical analysis of responses--

impractical. The analysis of survey results, thus, is of a general, descriptive nature.

The survey was conducted primarily by telephone using the interview guide cited earlier. Respondents were selected from referrals made by other respondents or by their supervisors. There was no attempt made to randomize selection of respondents; thus, from a statistical standpoint the results cannot be said conclusively to represent the views held by non-respondents. However, the consistency of answers provided makes this "problem" in the survey technique immaterial.

In length, the interviews varied from 5 to 20 minutes. The interviewer described the purpose of the survey as "to explore the amenability of various programs within the Armed Forces to adopt the use of Bayesian techniques in the reliability assessment process." To accomplish this end, the interviewee was told that we were seeking information regarding:

- the types of testing being conducted within his organization;
- the resources expended on testing;
- the obstacles that existed to introducing Bayesian techniques; and
- the potential test sites where the subject technique could be demonstrated.

A general discussion usually ensued during which the interviewer recorded the relevant information. When this discussion ended, the interviewer asked for answers to questions on the interview guide which had not been answered during the general discussion. The results of this process are presented in the following section.

III. FINDINGS OF SURVEY

In this section, we present a summary of the information gathered from the survey in sections corresponding to the subject areas of the interview.

A. TYPES OF TESTING

Generally speaking, reliability tests are performed during research and development phases, prior to and during initial production, and after storage or limited use. During development, tests are usually conducted by a contractor under a test plan agreed to by the government. As the items are developed to the pre-production phase, the Service typically takes more testing responsibility to ensure compliance under operational conditions.

Our questions centered around testing complete systems. In the main, these questions did not elicit a set of responses that could be generalized. Most persons queried could not really provide a description of their program in terms of developmental, production, or operational testing. Variations in terminology also masked the results. For example, field failures of equipment have made program managers keenly aware of the need to test equipment under operational or simulated operational conditions. Hence, operational tests do not always refer to tests of a system that has already been in use.

The interviews revealed that there is only a limited amount of reliability assessment accomplished for major assembled systems for several reasons:

- the MTBF's are too long to develop accurate estimates;
- the systems are too expensive to test to destruction;
- the reliability levels needed are thought to be too high to be demonstrated statistically;
- there is less interest in the point estimate of reliability and its confidence interval than in other facets of the system such as operability, ease of handling, and specific failure modes.

B. RESOURCES EXPENDED

Most of those interviewed were not aware of any efforts to collect or analyze data on the resources expended in reliability assessment, except with respect to individual program development efforts where the amount expended is contractually regulated. Even under contractual development efforts, however, there does not appear to be any guidance developed from past experience on how much should be spent on reliability assessment or how reliability assessment costs should be controlled.

Some interviewees commented that reliability assessment costs are not as easy to define as maintenance costs. Maintenance is ongoing and more readily costable. Other comments pointed to the difficulty of distinguishing between some engineering and equipment costs and reliability assessment costs. In a few cases, interviewees indicated that they could not answer questions on cost unless we could substantiate our "need to know."

One interviewee had just completed a cost study of 20 systems, all of which were developed under contract. His organization used a

questionnaire approach followed by interviews in order to standardize answers. The study resulted in empirical relationships between reliability costs and other variables such as type of contract, number of active parts, and number of deliverables. Copies of this report have not been made available as yet. Information can be obtained from: NAVSEA 06-G2, Washington, D.C. 20362.

C. BAYESIAN TECHNIQUES

Most of the persons interviewed who were familiar with Bayesian techniques, expressed some frustration at the problems or obstacles that prevented their implementation. For example, manufacturers may be loathe to try to work with new reliability acceptance standards when they are sure of a profit from the old ones. Moreover, Bayesian techniques are still strongly opposed by "classical" statisticians and, thus, are controversial. However, even among those interviewees who held to the classical view, there was an interest in seeing demonstrations conducted using Bayesian approaches.

Responses to questions concerning the barriers to the implementation of Bayesian techniques were possible to tabulate, as shown in Exhibit 5 on the following page. Some comments on the validity of the barriers were voiced. For example, a few interviewees felt that data applicability was not a serious limitation. They felt that, although it was true that field environments differ from test environments, the cost of testing systems in the

Exhibit 5

OBSTACLES TO THE IMPLEMENTATION OF BAYESIAN TECHNIQUES

Obstacle	Number of Mentions
1. Selection of prior is problematic	5
2. Data shortages and cost of retrieval are high	5
3. Component data are not applicable because of difference between test stand and operational conditions	5
4. Problem of acceptance of subjective judgment	4
5. Contractual difficulties	2

field is so high that one is forced to use whatever relevant data exists.

With respect to familiarity with Bayesian techniques, the answers were difficult to quantify because of the irregularity and overlaps in the nominal scales used. What can be said is that those thought to be familiar were only partially so. What constituted "familiarity" may have varied among interviewees.

All of the Services sponsor training programs in the acquisition process and in reliability techniques. With a few exceptions, such as the AFIT Master's Degree program, the courses are basic, and Bayesian techniques are not treated in any depth. The consensus seems to be, however, that there are knowledgeable persons throughout the research-oriented commands, at the Rome Air Development Center, and the Office of Naval Research, but a general void at the program monitoring and field testing levels. Most agreed that demonstration projects using Bayesian techniques either would be helpful or were critically needed. According to an interviewee in a coordinating role in the Army's reliability assessment network, "in certain areas we are being forced into the use of Bayesian techniques, especially with one-shot devices which must be destructively tested."

Most interviewees were concerned. Some who had been thinking of the problem suggested developing computer simulations of the test situation to substantiate the savings that could accrue. Others informed us

of the one or two applications that have been tried, and some suggested the types of systems (generally expensive and test-destroyable) that would be most suited to the application.

Several people reported on the many attempts to develop Bayesian material to be included in MIL STD 781 that have gone astray at the last minute. One reliability analyst reported on work conducted by a noted scholar describing Bayesian procedures for inclusion in MIL STD 781. The recommended procedures were later deemed inappropriate for the standards according to a review by another noted scholar.

Experience has shown that the Government must be protected from the choice of prior distributions which may bias the results in favor of the contractor's claims. This lesson was learned during development of SONAR equipment by General Electric. Those familiar with this situation suggested that a process for reaching consensus on prior distributions must be established.

One interviewee reported on being involved for three to four years in a Tri-Service group which attempted to develop applications of Bayesian statistics. He was not aware of the final disposition except that some of the methods were still being used at Picatinny Arsenal. One respondent at the Rome Air Development Center reported on an extensive publication, RADC-TR-76-294. This report does not deal with cost-effective testing, but it does deal in depth with Bayesian (and related) acceptance plans.

D. SYSTEM AND TEST CHARACTERISTICS

Two questions of interest are: (1) to what extent do the systems tested contain redundancies, and (2) to what extent is destructive testing used. Although these questions were addressed only selectively (many interviewees were not directly involved in testing a particular system), the answers are summarized in Exhibit 6 on the following page.

The question on "destructive tests" was actually too simplistic. The operationally oriented tests, performed by agencies such as AFTEC which represent the users' point of view, try to establish whether the equipment will pass or fail certain mission stresses. In such cases, if destruction occurs, it is not a planned part of the test. The fact that the survey was conducted across those involved in development as well as operational testing explains some of the variance in responses.

E. TECHNICAL ISSUES

A few technical issues were brought up by interviewees which could effect implementation of the method being studied. The first problem concerns the fact that prior test data on components may not be appropriate unless the stress environment to which the component was subjected duplicates what will exist in the system operation. Also, some failures may occur because of "interconnect" problems; that is, the components function but the mechanisms connecting them do not. While these certainly are problems, partial data, used judiciously, are better than no data at all. Also, the number of systems

Exhibit 6

SYSTEM REDUNDANCY AND USE OF DESTRUCTIVE TESTS

Redundancies		Destructive Tests	
Depends on the system	3	Not planned	4
Some have a lot	1	Occasionally	3
A lot do have some	3	Frequently	2
Not many	1	Hardly at all	2
Not answered	3	Depends on system	1

tests needed to discover these problems is surely less than that needed to establish reliability estimates for the entire system.

A second problem expressed by some interviewees was that systems are not tested on a component-by-component basis. They are tested as systems, but it is ultimately the components which fail. Hence, each system test amounts to a test on each component. What we are proposing is that there are more economical ways of testing the components and deriving system reliability estimates than by complete system tests.

In sum, a great deal of interest was sparked by the notion of optimal or cost-effective testing using Bayesian techniques. Persons in all four services agreed that the time has come to provide a systematic rationale for structuring test plans which considers the costs of testing and the value of the information obtained.

IV. SURVEY INSTRUMENT: RELIABILITY ASSESSMENT QUESTIONNAIRE

1. Type of testing

   Development ________%

   Production ________%

   Other ________%

2. Testing done by

   Military ________%

   Contractor ________%

3. Approximate $ per year absorbed by reliability assessment ________.

4. Who is usually the dominant force in determining the nature of the test plan?

   Program Officer ________

   Contractor ________

   Other ________

5. Familiarity of program officers with Bayesian techniques:

Some	Very ________	Partially ________
Half	Very ________	Partially ________
Most	Very ________	Partially ________
Hardly Any	Very ________	Partially ________

6. Obstacles or barriers to the implementation of Bayesian techniques.

7. Suggestions for overcoming barriers.

8. Applications using Bayesian techniques in test plan development.

9. Methods of introducing innovative approaches in testing.

10. **Demonstration projects using Bayesian techniques for the formulation of test plans:**

Are critically needed	________
Are sorely needed	________
Could be helpful	________
Would be of little use	________

11. Rank these barriers:

Program Officer knowledge	____________
Contractual problems	____________
Selection of appropriate prior distribution	____________
Lack of acceptance of Bayesian techniques	____________

12. Does your command do reliability testing of operational systems?

13. Are these system tests done on a component-by-component basis?

Component-by-component	____________
System Use Test	____________
Other (specify)	

____

____

14. To what extent do systems you deal with contain redundancies?

15. To what extent is destructive testing used in your command:

Frequently	____________
Occasionally	____________
Hardly at all	____________

16. Are destructive tests performed on components of production systems?

17. Does your command maintain any cost data on testing? Explain.

18. What is the possibility of demonstrating a sequential Bayesian test scheme in your command?

DATE: ____________________

NAME: ____________________

ORGANIZATION: ____________________

____

PART 5

BRIEFING SLIDES ON PROJECT REPORT

PART 5

PROJECT REPORT

DEVELOPMENT AND EVALUATION OF A BAYESIAN SEQUENTIAL TESTING METHODOLOGY FOR ASSESSING THE RELIABILITY OF DEFENSE SYSTEMS

February 1, 1978

DECISIONS AND DESIGNS, INC.

MAXIMUS, INC.

MAXIMUS

OUTLINE OF PRESENTATION

I. BACKGROUND OF PROJECT

II. SURVEY OF SERVICE RELIABILITY ASSESSMENT PROGRAMS

III. REVIEW OF OPTIMAL TESTING METHODOLOGY

IV. INTRODUCTION TO ABRAM3 COMPUTER PROGRAM

V. DESCRIPTION OF ARMY ARMAMENT MATERIAL READINESS COMMAND

VI. SYSTEM SELECTED AND APPROACH TAKEN

VII. PHASE II PROPOSAL

I. BACKGROUND OF PROJECT

- OBJECTIVES OF THE PROJECT
- PRINCIPAL PARTICIPANTS
- PROJECT TASK PLAN AND SCHEDULE

OBJECTIVES OF THE PROJECT

- TO DEMONSTRATE THE DOLLAR SAVINGS THAT CAN BE ACHIEVED BY USING BAYESIAN RELIABILITY ASSESSMENT TECHNIQUES FOR:
  - OPTIMALLY TESTING A SYSTEM
  - COMBINING COMPONENT AND SYSTEM TEST DATA TO REDUCE SAMPLE SIZES
- TO DEVELOP A COMPUTER SOFTWARE PACKAGE WHICH CAN BE USED TO IMPLEMENT THE TECHNIQUES

PRINCIPAL PARTICIPANTS

- MAXIMUS, INC.
- DECISIONS AND DESIGNS, INC.
- ADVANCED RESEARCH PROJECTS AGENCY
- U.S. ARMY ARMAMENT MATERIEL READINESS COMMAND (ARRCOM)
  - MR. LOUIS IANNUZELLI - ARRCOM POINT OF CONTACT
  - MR. ROBERT MCKEAGUE - ARRCOM PROJECT DIRECTOR
  - MR. JOHN OBREN - DIRECTOR OF PRODUCT ASSURANCE

PROJECT TASK PLAN AND SCHEDULE

TASK DESCRIPTION	TASK SCHEDULE START MONTH	TASK SCHEDULE END MONTH
1. REVIEW CURRENT SERVICE TESTING PROGRAMS AND REFINE METHODOLOGY	MAY	SEPTEMBER
2. DEVELOP COMPUTER PROGRAMS FOR IMPLEMENTING METHODOLOGY (ABRAM3)	SEPTEMBER	OCTOBER
3. SELECT TESTING ORGANIZATION AND INSTRUCT STAFF (ARRCOM)	OCTOBER	NOVEMBER
4. EVALUATE ORGANIZATION'S EXPERIENCE WITH METHODOLOGY	DECEMBER	MARCH

II. SURVEY OF SERVICE RELIABILITY ASSESSMENT PROGRAMS

- SAMPLE OF PERSONS/ORGANIZATIONS CONTACTED
- ATTITUDES TOWARD THE IMPLEMENTATION OF BAYESIAN TECHNIQUES
- GENERAL CONCLUSIONS DRAWN FROM THE SURVEY
- TASK 1 REPORT HIGHLIGHTS

SAMPLE OF PERSONS/ORGANIZATIONS CONTACTED

MR. D. ANDERSON	DDR&E(T&E)	MR. L. CROW	AAMSA
COL. B. SWETT	DDR&E(T&E)	MR. A. NORDSTRUM	DARCOM
MAJ. G. MORGAN	AFSC/SDDE	MR. H. BALABAN	ARINC, INC.
MR. M. WILLIAMS	AFTEC/OA	MR. J. CIPRIANO	NAVSEA
MR. T. PETTINATO	AFSC/RADC	MR. M. BUCKBERG	NAVSEA
MR. T. ATHENS	AFLC/SAALC	MR. H. ITKIN	NAVSEA
MR. J. KLION	AFSC/RADC	DR. B. ORLEANS	NAVSEA
CAPT. H. LAFLAME	AF/DCS/P&O	MR. B. MCDONALD	ONR
MR. T. COPPOLA	AFSC/RADC	MR. W. WALLACE	NAVELEX
COL. J. HAGER	AFSAB	MR. K. LASALLA	NMAT
MR. L. IANNUZELLI	ARRCOM	MR. M. LANDIS	NAVSEA
MAJ. N. CHRISCIMAGNA	AF/DCS/SL	COL. G. O'BANION	AFTEC
MR. DAVID BARBER	AFSC/RADC	MR. R. MCKEAGUE	ARRCOM
DR. I. SHIMI	AFOSR	MR. JOHN CARR	USMC/MCTSSA

ATTITUDES TOWARDS IMPLEMENTATION OF BAYESIAN TECHNIQUES

- SOME PERSONS ARE IN FAVOR OF MODIFYING MILITARY STANDARDS TO ENCOURAGE THE USE OF BAYESIAN TECHNIQUES
- SOME ARE SKEPTICAL OF THE TECHNIQUES SINCE THEY APPEAR VERY SOPHISTICATED
- SOME ARE STRONG ADVOCATES OF THE TECHNIQUES AND PARTICIPATE IN RELIABILITY CONFERENCES SPONSORING BAYESIAN ANALYSES
- SOME BELIEVE THE TECHNIQUES GIVE THE CONTRACTOR TOO MUCH LEEWAY AND LEAVE THE GOVERNMENT AT RISK
- SOME ARE SIMPLY AFRAID TO USE BAYESIAN TECHNIQUES BECAUSE OF THE TROUBLE AND POSSIBLE CONTROVERSY
- AND THERE ARE SOME WHO ARE ADAMANTLY OPPOSED TO THE USE OF BAYESIAN TECHNIQUES

CONCLUSIONS FROM SURVEY ON TEST & EVALUATION ACTIVITIES

- RELIABILITY ASSESSMENT OF SYSTEMS IS CARRIED OUT DURING DEVELOPMENT, PRODUCTION, AND OPERATIONAL PHASES.

- EMPHASIS OF ASSESSMENT IS ON THE ELIMINATION OF FAILURE MODES, QUALITY ASSURANCE, FIELD USE, AND IMPROVED SYSTEM MAINTAINABILITY

- RELIABILITY ASSESSMENT METHODOLOGIES USED BY THE SERVICES ARE, FOR THE MOST PART, NOT STATE-OF-THE-ART

- MILITARY STANDARDS ARE CONTINUALLY BEING REVISED BY AD HOC GROUPS CONVENED TO REEXAMINE THE STANDARDS.

- NO FORMALIZED PROCEDURES FOR TESTING SYSTEMS OPTIMALLY HAVE BEEN DEVELOPED

- VERY LITTLE DATA COLLECTED ON THE COSTS OF TESTING OR ON THE COSTS OF MISESTIMATION

TASK 1 REPORT HIGHLIGHTS

- PROVIDES NAMES AND ORGANIZATIONS OF KEY PEOPLE
- WILL SERVE AS A REFERENCE FOR RELIABILITY PERSONNEL
- BOUND IN DRAFT FORM SO IT CAN BE EDITED BY SERVICES
- MAY STIMULATE MORE INTERACTION AND COOPERATION AMONG AND WITHIN THE SERVICES

III. REVIEW OF OPTIMAL TESTING METHODOLOGY

- WHAT IS MEANT BY OPTIMAL TESTING?
- BAYESIAN APPROACH TO OPTIMAL TESTING
- WHY COMBINE COMPONENT AND SYSTEM TEST DATA?
- ASSESSMENT APPROACH ADOPTED

WHAT IS MEANT BY OPTIMAL TESTING?

OPTIMAL TESTING MEANS THAT INFORMATION ON RELIABILITY IS OBTAINED AT THE MOST COST-EFFECTIVE RATE

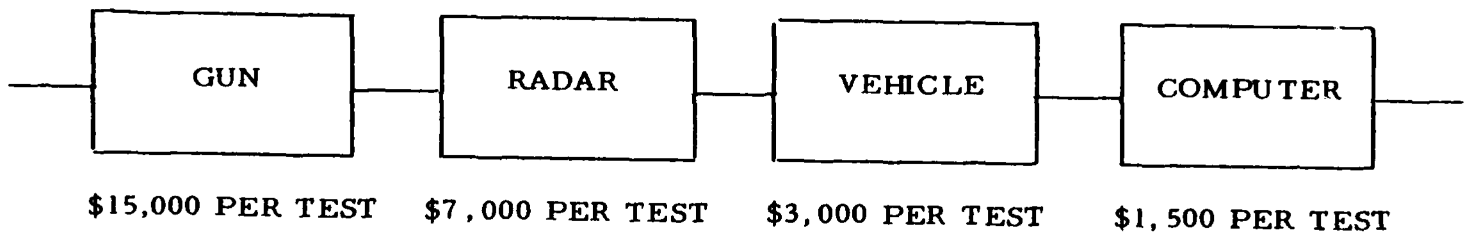
IF SOME COMPONENTS ARE MORE IMPORTANT THAN OTHERS TO THE FUNCTIONING OF THE SYSTEM;

SOME COMPONENTS HAVE HISTORICAL DATA AVAILABLE WHICH INDICATE HOW RELIABLE THEY ARE; AND

SOME COMPONENTS COST MORE TO TEST THAN OTHERS

THEN, SOME COMPONENTS SHOULD BE TESTED MORE THAN OTHERS.

<u>EXAMPLE:</u> <u>SYSTEM TEST BUDGET IS $600,000</u>

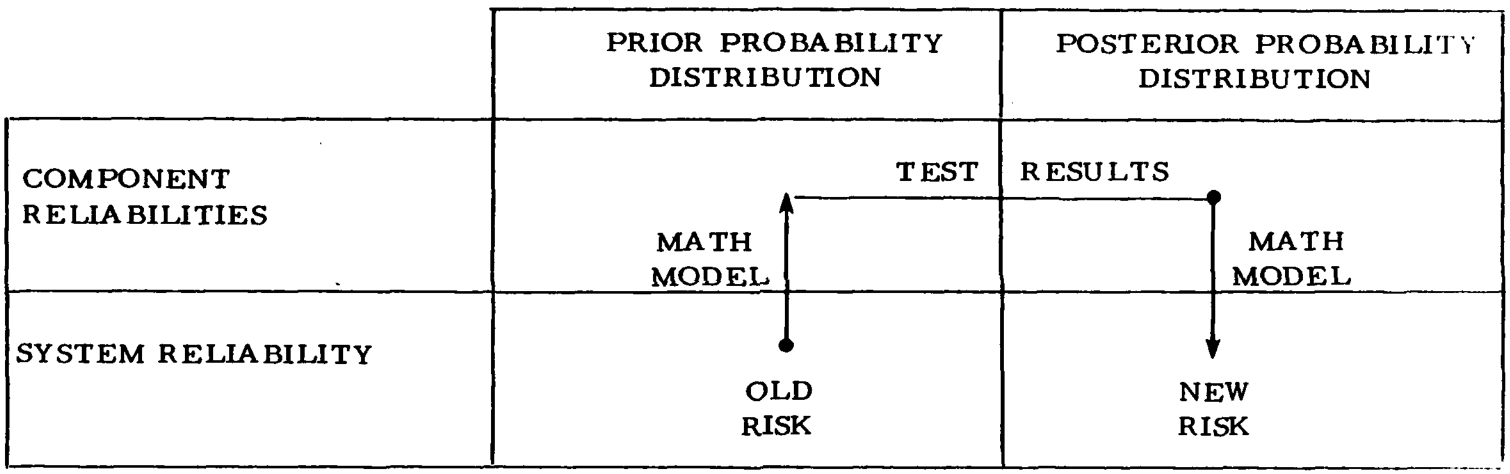


HOW MANY TIMES SHOULD EACH COMPONENT BE TESTED?

BAYESIAN APPROACH TO OPTIMAL TESTING

- KNOWLEDGE OF RELIABILITY IS EXPRESSED AS A PROBABILITY DISTRIBUTION
- BEST ESTIMATE OF RELIABILITY IS THE MEAN OF THE DISTRIBUTION
- RISK ASSOCIATED WITH THE BEST ESTIMATE IS PROPORTIONAL TO THE VARIANCE OF THE DISTRIBUTION
- THE PURPOSE OF TESTING IS TO REDUCE THE VARIANCE OF THE SYSTEM RELIABILITY DISTRIBUTION
- OBJECTIVE OF METHODOLOGY IS TO REDUCE THE VARIANCE COST EFFECTIVELY

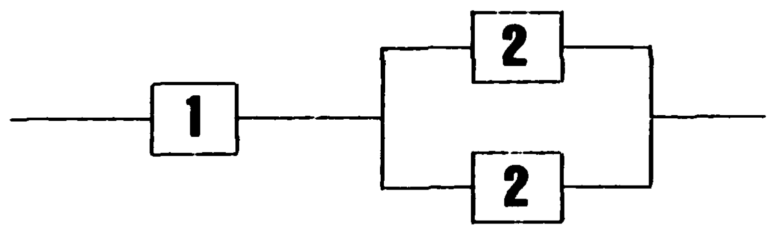
SEQUENCE OF ANALYSIS



WHY COMBINE COMPONENT & SYSTEM TEST DATA?

- COMPONENT TEST DATA ARE AVAILABLE ON ALMOST EVERY SYSTEM

- SYSTEM TEST DATA ARE ALSO AVAILABLE, BUT PROVIDE INCOMPLETE INFORMATION ON COMPONENTS



- USING ALL DATA PROVIDES A MORE COST-EFFECTIVE ASSESSMENT

ASSESSMENT APPROACH ADOPTED

- PRIOR DISTRIBUTION OF SYSTEM RELIABILITY IS SPECIFIED BY THE GOVERNMENT
- SYSTEM TEST RESULTS ARE USED TO UPDATE THIS PRIOR DISTRIBUTION
- PRIOR DISTRIBUTION OF COMPONENT RELIABILITIES ARE DETERMINED FROM THE UPDATED PRIOR DISTRIBUTION OF SYSTEM RELIABILITY
- POSTERIOR DISTRIBUTION OF COMPONENT RELIABILITIES ARE COMPUTED USING COMPONENT TEST RESULTS
- POSTERIOR DISTRIBUTION OF SYSTEM RELIABILITY IS COMPUTED USING POSTERIOR DISTRIBUTIONS OF COMPONENT RELIABILITIES

IV. INTRODUCTION TO ABRAM3 COMPUTER PROGRAM

- COMPUTATIONAL REQUIREMENTS OF METHODOLOGY
- AUTOMATIC RELIABILITY MODEL GENERATOR
- CONFIGURATION CODING SCHEME FOR COMPONENTS
- PROGRAM FLOW CHART
- INPUT DATA FOR PROGRAM
- OUTPUT DATA OBTAINED

COMPUTATIONAL REQUIREMENTS OF OUR METHODOLOGY

- MUST BE ABLE TO WORK BACK AND FORTH BETWEEN KNOWLEDGE OF THE SYSTEM RELIABILITY AND KNOWLEDGE OF THE COMPONENT RELIABILITIES

- MUST BE ABLE TO COMPUTE THE EXPECTED VALUE OF THE RISK THAT WILL RESULT IF A PARTICULAR COMPONENT IS TESTED

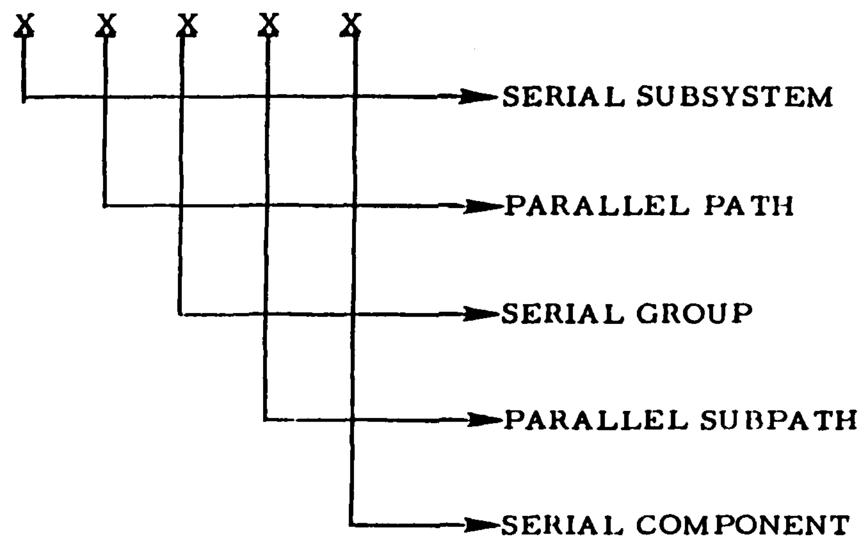
- MUST BE ABLE TO IDENTIFY THE COMPONENT WHICH REDUCES THE EXPECTED RISK AT LEAST COST

- MUST BE ABLE TO TREAT MULTIPLE TESTS OF THE SAME COMPONENT

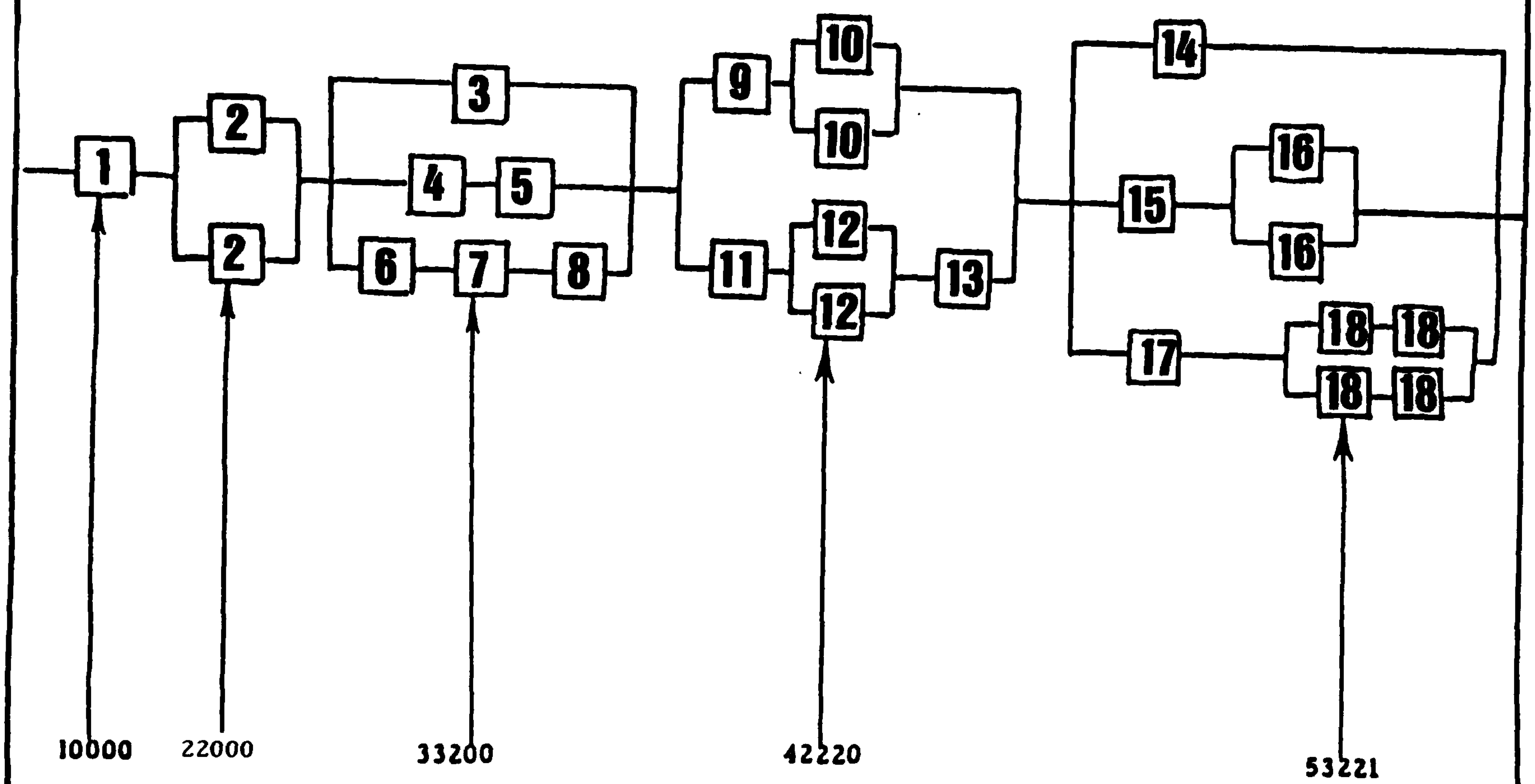
MAXIMUS

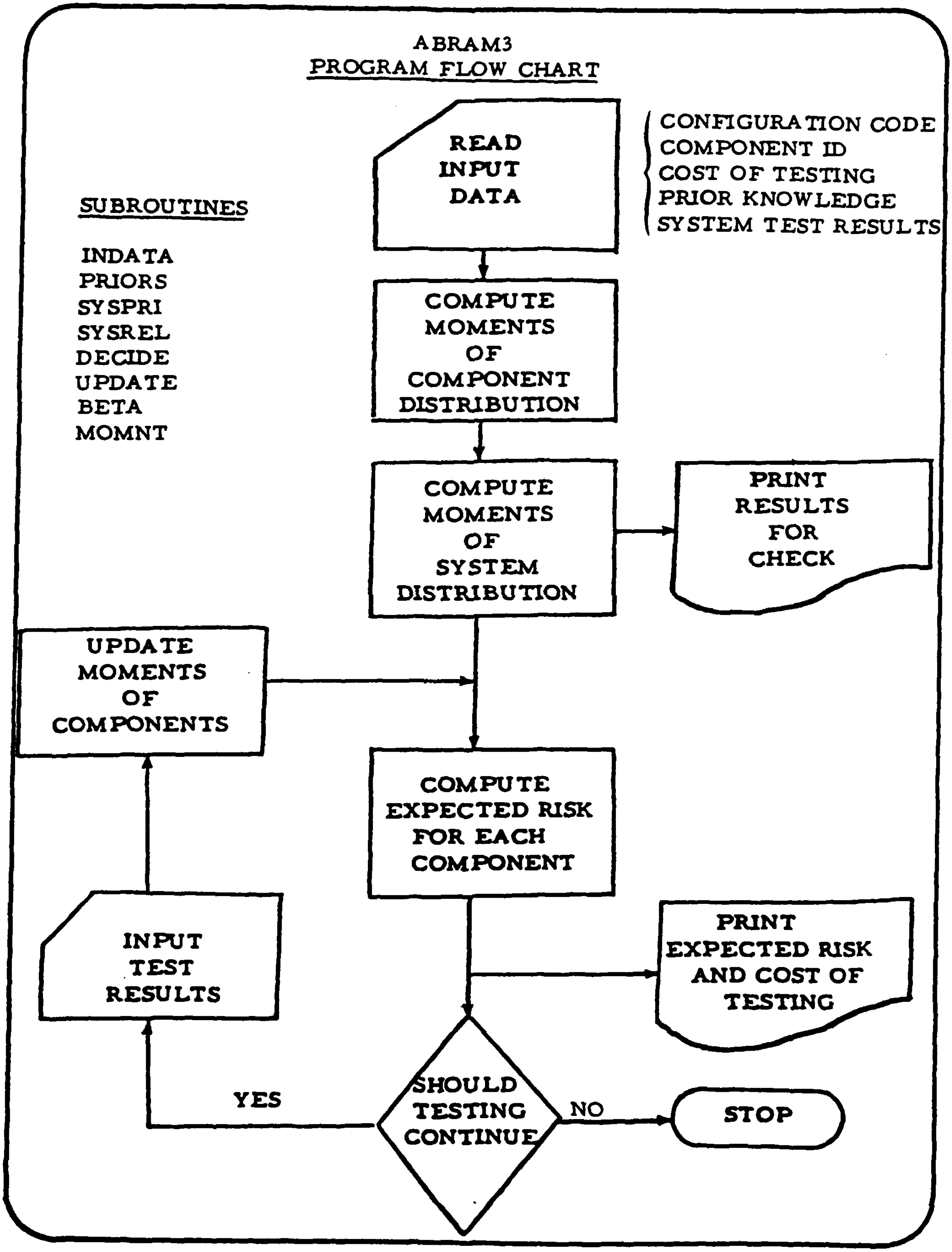
AUTOMATIC RELIABILITY MODEL GENERATOR

- NEED TO HAVE A METHOD OF CALCULATING
  - SYSTEM RELIABILITY FROM COMPONENT RELIABILITIES
  - COMPONENT RELIABILITIES FROM SYSTEM RELIABILITY
- DEVELOPED A CONFIGURATION CODING SCHEME USING FIVE DIGITS TO AUTOMATE CALCULATIONS



COMPONENT CONFIGURATION CODE XXXXX




ABRAM3
PROGRAM FLOW CHART
SUBROUTINES
INDATA
PRIORS
SYSPRI
SYSREL
DECIDE
UPDATE
BETA
MOMNT
READ INPUT DATA
CONFIGURATION CODE
COMPONENT ID
COST OF TESTING
PRIOR KNOWLEDGE
SYSTEM TEST RESULTS
COMPUTE MOMENTS OF COMPONENT DISTRIBUTION
COMPUTE MOMENTS OF SYSTEM DISTRIBUTION
PRINT RESULTS FOR CHECK
UPDATE MOMENTS OF COMPONENTS
COMPUTE EXPECTED RISK FOR EACH COMPONENT
INPUT TEST RESULTS
PRINT EXPECTED RISK AND COST OF TESTING
YES
SHOULD TESTING CONTINUE
NO
STOP

INPUT DATA FOR PROGRAM

MAX = NUMBER OF CONFIGURATION CODE ENTRIES

ICMAX = NUMBER OF DISTINCT COMPONENTS

IC(I) = CONFIGURATION CODE FOR ENTRY I,

ICN(I) = COMPONENT NUMBER FOR ENTRY I

ICOST(I) = COST OF TESTING THE COMPONENT ENTRY I

NUMPRI = NUMBER OF PRIOR DISTRIBUTIONS TO BE SPECIFIED

IA(J) = PSEUDO SUCCESSES FOR JTH COMPONENT

IB(J) = PSEUDO FAILURES FOR JTH COMPONENT

CARD #1

1	2	3	4	5	6
0	4	5	0	2	2
MAX			ICMAX		

CARD #2

•
•
•

1	2	3	4	5	6	7	8	9	10
0	0	0	0	0	0	0	0	0	0
IC					ICN		ICOST		

CARD #MAX+1

1	2	3	4	5	6	7	8	9	10
3	1	2	1	4	1	8	7	8	5
IC					ICN		ICOST		

CARD #MAX+2

1	2	3
0	0	1
NUMPRI		

CARD #MAX+ NUMPRI

1	2	3	4	5	6	7	8	9
2	1	4	2	3	0	5	0	0
IC					IA		IB	

OUTPUT DATA FROM PROGRAM

CURRENT ESTIMATE OF RELIABILITY IS 0.50

CURRENT ESTIMATE OF RISK IS 8333

COMPONENT TO BE TESTED	EXPECTED VALUE OF RISK	$ COST PER UNIT REDUCTION
1	7910	$ 750
2	6530	$ 210
3	7250	$1750
4	7825	$1500
5	8240	$ 650
6	6320	$2900

NEXT COMPONENT TO BE TESTED IS NUMBER 2.

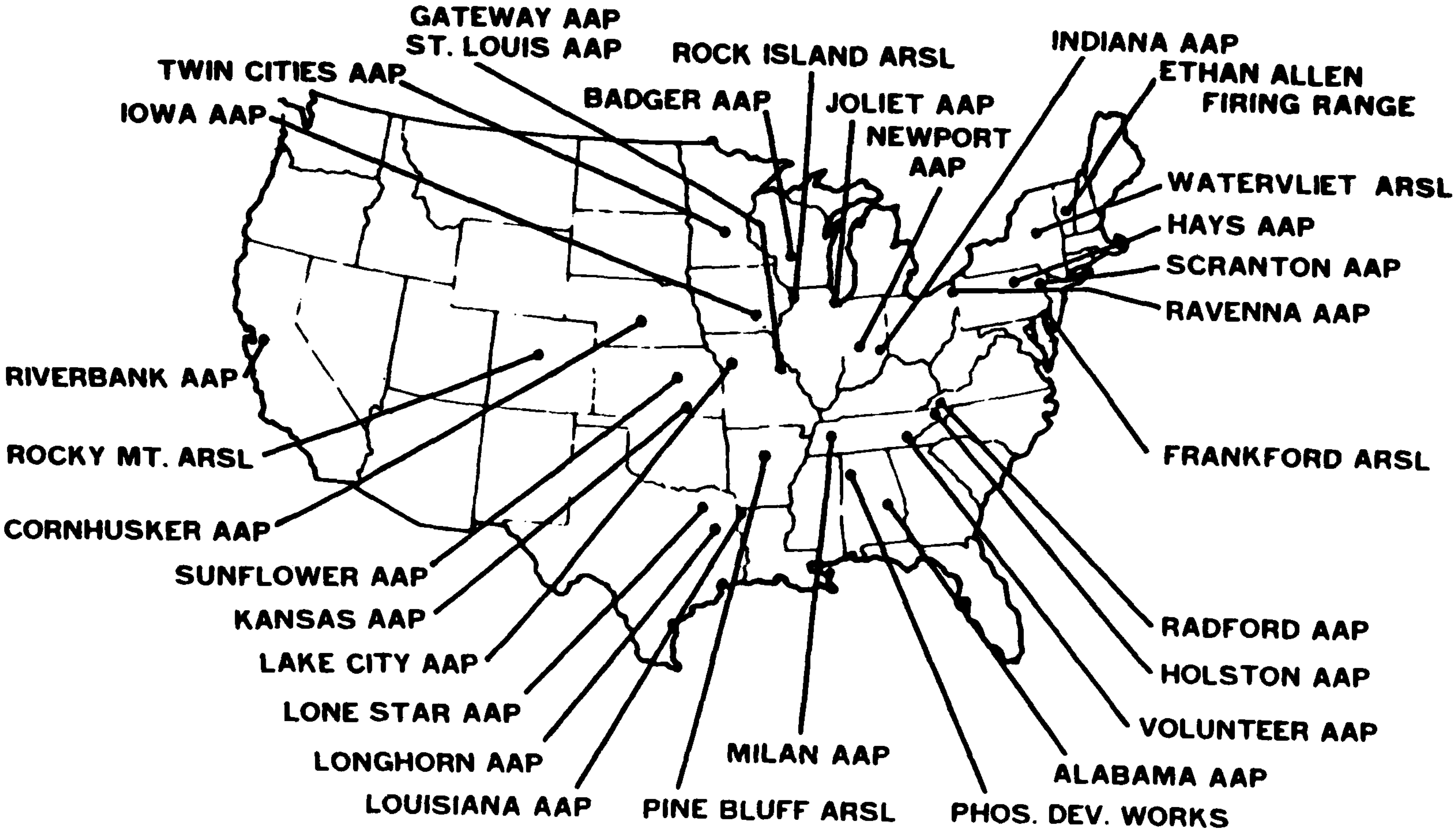
V. ARMY ARMAMENT MATERIAL READINESS COMMAND (ARRCOM)

- MISSION AND RESOURCES OF ARRCOM
- INSTALLATIONS AND ACTIVITIES
- PRODUCT ASSURANCE DIRECTORATE

MISSION AND RESOURCES

- UNDER DARCOM (U. S. ARMY MATERIEL DEVELOPMENT AND READINESS COMMAND)
- RESPONSIBLE FOR LOGISTICAL SUPPORT OF ARMAMENT MATERIEL
- ARMAMENT MATERIEL ASSIGNMENTS
  - TOWED AND SELF-PROPELLED ARTILLERY
  - MORTARS AND RECOILLESS RIFLES
  - ROCKET LAUNCHERS
  - INDIVIDUAL AND CREW-SERVED WEAPONS
  - AIRCRAFT ARMAMENT
- BUDGET: $3 BILLION PER YEAR
- PERSONNEL: 12,600

ARRCOM INSTALLATIONS AND ACTIVITIES



PRODUCT ASSURANCE DIRECTORATE

MR. JOHN OBREN

- PLANS AND PROGRAMS ANALYSIS DIVISION
- QUALITY ENGINEERING DIVISION
- METHODOLOGY AND DATA SYSTEMS DIVISION
- RELIABILITY AND MAINTAINABILITY DIVISION
- RAM ASSESSMENT DIVISION*
- WEAPONS QUALITY OPERATIONS DIVISION
- MUNITIONS QUALITY OPERATIONS DIVISION
- SURVEILLANCE OPERATIONS DIVISION

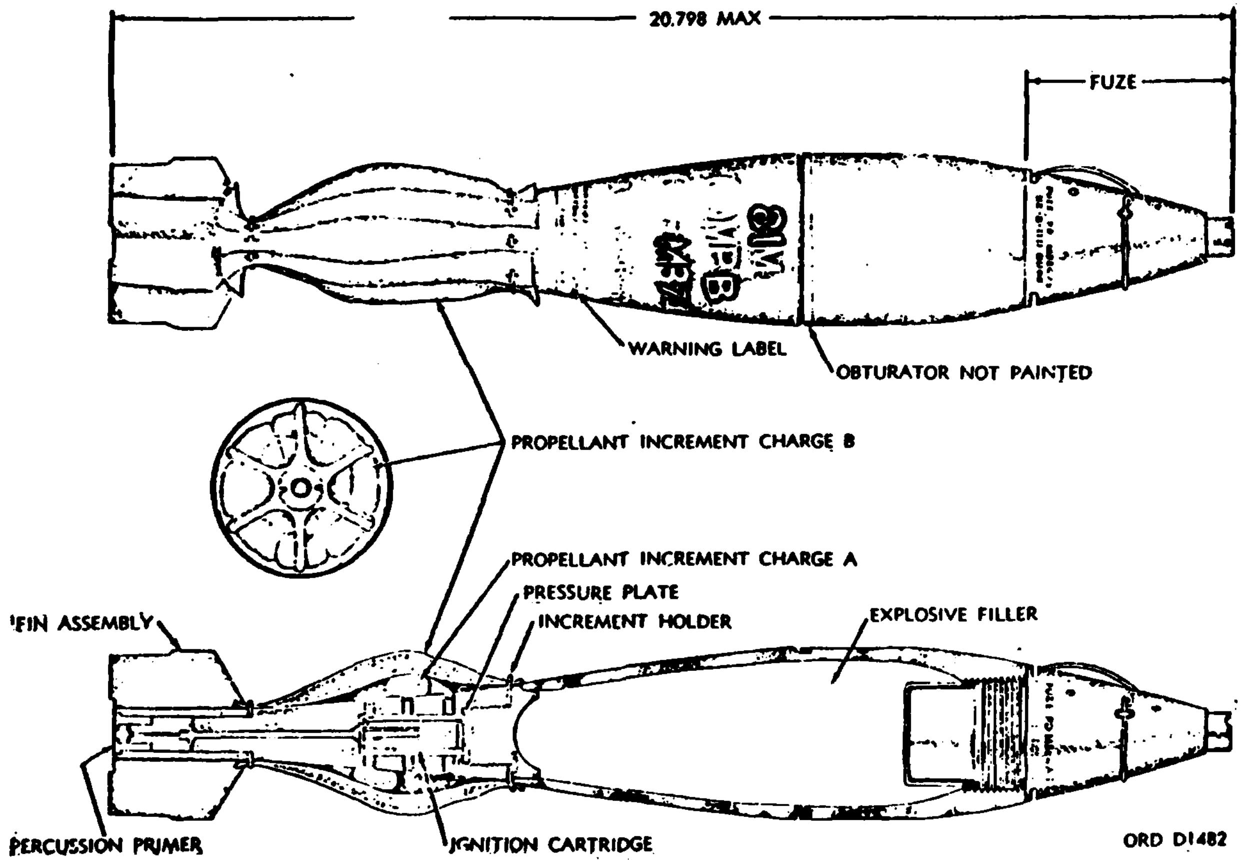
VI. SYSTEM SELECTED AND APPROACH TAKEN

- SYSTEM SELECTION CRITERIA
- SYSTEM RECOMMENDED BY ARRCOM
- OBSERVATIONS FROM STUDYING MILITARY STANDARDS ON SYSTEM COMPONENTS
- DATA COLLECTION FORMS
- APPROACH TO REFINE METHODOLOGY
- WORK REMAINING TO BE ACCOMPLISHED

SYSTEM SELECTION CRITERIA

- COST OF TESTING SHOULD BE OF CONCERN
- SYSTEM SHOULD HAVE SUBSYSTEMS COMPOSED OF A NUMBER OF COMPONENTS/ASSEMBLIES
- SYSTEM SHOULD BE RELATIVELY SIMPLE SO THAT RESULTS CAN BE EASILY OBTAINED
- DATA SHOULD BE AVAILABLE ON THE NUMBER OF TESTS BEING CONDUCTED ON THE SYSTEM AND ITS COMPONENTS
- TESTING SHOULD BE PASS-FAIL RATHER THAN TIME-TO-FAIL

SYSTEM RECOMMENDED: 81-MM HE CARTRIDGE M374



COMPONENTS OF THE 81-MM HE CARTRIDGE M374

- M524 FUSE
  - METAL PARTS FOR M524
  - M2 DELAY ELEMENT
  - M63 DETONATOR
  - M80 DETONATOR
- 81-MM PROJECTILE
- COMPOSITION B EXPLOSIVE
- M-90 PROPELLANT INCREMENT
  - M-26 PROPELLANT
  - INCREMENT BAGS
- M285 IGNITION CARTRIDGE
- M71 PERCUSSION PRIMER
  - M71 PRIMER PARTS
  - M35 PRIMER PARTS
  - BLACK POWDER
  - GRAPHITE
- M2A1 AND M3 INCREMENT HOLDERS
- M170 FIN ASSEMBLY

4.4.3 Testing.

4.4.3.1 Chemical sampling. - A representative sample shall be randomly selected for the chemical tests specified in 4.5. The procedure described in ASTM E300 should be used to withdraw the samples. The chemical tests in 4.5 shall be performed using prescribed analytical procedure for replicate determination given in standard analytical textbooks.

4.4.3.2 Moisture.

*4.4.3.2.1 Moisture content of lead azide (see 3.4) - Major A defect. - The moisture content of the lead azide shall be determined for each lot at the time of loading. A sample in sufficient quantity to perform the test detailed in 4.5.1 shall be selected and tested as specified in 4.5.1. If the moisture content is in excess of the percentage specified and loading has not begun, the lot of lead azide shall be rejected. If loading has begun, action on the unloaded lead azide shall be as specified above and all detonators loaded with questionable lead azide shall be rejected.

4.4.3.3 Binder-lubricant content of RDX (see dwg. 8798731) - Major A defect. - The binder-lubricant content of the RDX shall be determined for each lot at the time of loading. A sample of 5 grams shall be selected from each lot and tested as specified in 4.5.2. If the binder-lubricant content is in excess of the percentage specified and if loading has not begun, the lot of RDX shall be rejected until proper corrective action has been accomplished as verified by repeating the binder-lubricant determination specified in 4.5.2. If loading has begun, action on the unloaded RDX shall be as specified above and all detonators loaded with the questionable RDX shall be rejected.

4.4.3.4 Functioning

4.4.3.4.1 Output (see 3.5.1) Major A defect. - A sample of 315 detonators shall be selected at random from each lot. If 3 or more detonators fail to comply with the requirements specified, the lot shall be rejected. If one or two defectives are found, a second sample of 315 detonators shall be selected at random and tested. If in the combined first and second sample a total of 4 or more defectives are found the lot shall be rejected. The test shall be performed as specified in 4.5.3.2 using test equipment as specified in 4.4.4.

ARPA Contract

MAXIMUS
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FY77 PRODUCTION DATA FOR 81-MM CARTRIDGE M374

MAXIMUS Code	Item/Assembly Designation	Manufacturer Assembler of Item	Average Production Lot Size	Number of Lots in FY 77 that were:		Cost of Item/Assembly
				Accepted	Rejected	

FY 77 TEST DATA FOR 81-MM HE CARTRIDGE M374

MAXIMUS Code	Item/Assembly Designation	Types of Tests* Conducted	Sample Size Per Lot For Each Test: First Article or Start-Up	Sample Size Per Lot For Each Test: Continuous Production	Sample Size Per Lot For Each Test: Proving Ground	Rejection Criteria: No. Defective	Estimated Cost of Each Test

* Classify as: (1) Functioning, (2) Chemical Composition, (3) Shock/Vibration, (4) Temperature/Humidity, (5) Structural Integrity, (6) Visual Inspection, (7) Other

OBSERVATIONS FROM MILITARY STANDARDS

- NO EVIDENCE OF A MASTER TEST PLAN FOR COORDINATING OR INTEGRATING TESTS OF THE M374
- RESULTS OF TESTS ON SUCCESSIVE PRODUCTION LOTS ARE ASSUMED TO BE STATISTICALLY INDEPENDENT
- NO DATA COLLECTED ON THE COST OF TESTING
- DEDICATION TO PRODUCT ASSURANCE MOTIVATED EXPENSIVE AND EXTENSIVE TESTING
- RELIABILITY GOALS FOR EACH ITEM/ASSEMBLY NOT SPELLED OUT IN THE STANDARDS

FACTORS CONSIDERED IN ADAPTING THE METHODOLOGY FOR PRODUCTION TESTING

- CONTINUOUS PRODUCTION PROVIDES HISTORICAL DATA ON TEST RESULTS OF LOTS
  - SUPPORTS A BAYESIAN METHODOLOGY
  - SUPPORTS CONCEPT OF SEQUENTIAL TESTING
- MULTIPLE PRODUCTION LINES FOR DIFFERENT ITEMS/ ASSEMBLIES
  - SUPPORTS CONCEPT OF COMBINING COMPONENT AND SYSTEM DATA
  - SUGGESTS AN OPTIMIZATION APPROACH
- EXTENSIVE TESTING OF EACH ITEM/ASSEMBLY
  - SUGGESTS COSTS OF TESTING NOT FORMALLY CONSIDERED
  - SUGGESTS SAMPLE SIZES CAN BE REDUCED EVEN ON A SINGLE PRODUCTION LINE

WORK REMAINING TO BE ACCOMPLISHED IN PHASE I

- DEVELOP USER'S MANUAL FOR ABRAM
- DEVELOP ESTIMATES OF THEORETICAL SAVINGS
- INCORPORATE SERVICE COMMENTS INTO TASK 1 REPORT
- PREPARE FINAL REPORT

VII. PHASE II PROPOSAL

TASK 1: SELECT A NUCLEAR PROJECTILE AND COLLECT DATA ON THE CURRENT TESTING PROGRAM AND RELIABILITY ASSESSMENT PROCEDURES

TASK 2: CONDUCT A SYSTEMS ANALYSIS OF THE DATA ON BOTH THE NUCLEAR PROJECTILE AND THE CONVENTIONAL PROJECTILE

TASK 3: REFINE THE BAYESIAN METHODOLOGY TO INCORPORATE THE FINDINGS OF THE SYSTEMS ANALYSIS

TASK 4: DEVELOP A COST BENEFIT MODEL (LOSS FUNCTION) FOR SETTING THE OPTIMAL LEVEL OF CONSUMER'S AND PRODUCER'S RISK

TASK 5: EXPAND THE ABRAM SOFTWARE PACKAGE TO INCLUDE FEATURES OF THE REFINED METHODOLOGY AND UPDATE THE USER'S MANUAL

TASK 6: COMPUTE THE TEST COSTS AND RESULTS THAT CAN BE ACHIEVED WITH THE NEW METHODOLOGY AND COMPARE WITH PREVIOUS RESULTS

TASK 7: DEVELOP RECOMMENDATIONS FOR IMPLEMENTING THE NEW METHODOLOGY IN THE TESTING PROGRAMS AND PREPARE THE FINAL REPORT

END

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